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Assessing Impacts of Hydroelectric Dams in the Amazon Fluvial Basin

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Assessing Impacts of Hydroelectric Dams in the Amazon Fluvial Basin

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Abstract

Assessing Impacts of Hydroelectric Dams in the Amazon Fluvial Basin

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The amount of water the Amazon River delivers to the Atlantic Ocean every day is enough to supply New York City's fresh water needs for 9 years. This is soon to change with the race to choke the Amazon Basin with large hydrologic dams. Although studies investigating single dams can provide great analysis on a couple key issues, they often fail to consider these effects on the systems entirety. Without linking the physical and social components, one fails to fully understand the impacts of hydroelectric dams and therefore the vulnerability of the basin. The focus of this study is based on three forms of investigation: [1]a comprehensive literature review including scholarship on hydroelectric dams, basis characteristics, protected areas, and political characteristics within the respective countries; [2]data procurement of the physical geography of 20 sub-basins, 1,100 tributaries, and land use-land change (LULC) data; and together [3]the creation of a multivariable database integrated with GIS (geographic information systems) in order to better interpret human/nature complexities. Combined, this database

will be a powerful tool to assess vulnerability and risks associated with individual dams sites within a larger system. In addition, this database can be adjusted in the future such that when impacts of planned dams are actualized they can be recorded, and based of shared attributes of other dams in the database, this information can be correlated to make better predictions of new impacts.

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Introduction

Human-environment interactions are dynamic and vary based on spatial and temporal scales. New information on environmental impacts has shed light on disparities between places that focus on conservation, and those in the process of heavily modifying their natural systems. Certain discourses look at social issues relating to the global north-south divide to explain these disparities (Chichilnisky 1999) (Miraftab 2009) (Galeano 1971). At the same time, several environmental groups are examining the environmental pressures faced by the global south; specifically the tropics (Geist et al. 2002) (Skole et al 1993) (Kaimowitz et al. 1998) (Skole and Tucker 1993). Until recently, impacts on tropical rivers have been confined to a limited audience within academia. Compounding an already narrow audience, it is acknowledged that the knowledge base of tropical rivers is still limited (Latrubesse et al. 2005). This may seem alarming considering the tropics are home to eight of the ten largest rivers in the world (Latrubesse 2008).

Of the many human-induced impacts facing rivers today, the construction of large hydroelectric dams disproportionally affects the tropics (World Commission on Dams, 2000, Brandt, 2000, McCully 2001). While dams are actually being removed in the global north, construction in the tropics is booming (McCully 2001, AmericanRivers.org, Grant, 2001). This impulsive race to dam large tropical rivers is expected to cause imbalances and ultimately induce disastrous environmental and social consequences. Moreover, these consequences will be felt at different spatial (local to global) and temporal scales (pre-construction, to post construction).

Arguably the most charismatic river basin being affecting by hydroelectric dams is the Amazon Basin. Boasting a drainage area of covering 5% of the land area on earth (6×10^6 km^2) and a mean annual discharge of $210 \times 10^3 m^3/s$ (~20% of the annual global fresh water discharge to the ocean), the health of the Amazon River system is of local and global importance. However, even the Amazon's size cannot protect it from experiencing the effects of human impact. As the race to construct some ~285 large (over 2MW) hydroelectric dams within its basin continues, the Amazon's functions are at risk (see Figure 1 for spatial reference).

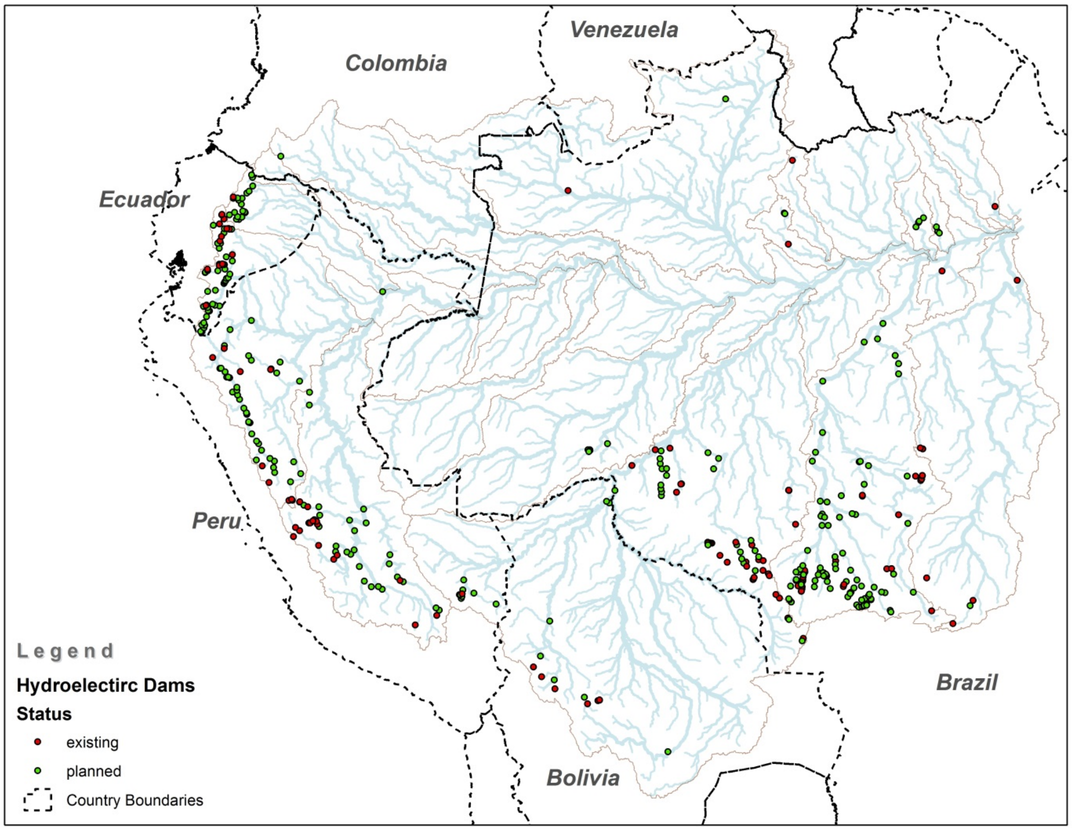


Figure 1: Planned and Existing Dams in the Amazon Basin

The purpose of this study is to assess the impacts of hydroelectric dams by major sub-basins across the Amazon Basin and identify comparative vulnerabilities. To do so, this study divides the Amazon Basin into 20 major sub-basins for relative comparisons. Factors considered within this study are intended to quantify basin characteristics of both physical attributes (e.g. biomes, land use land change (LULC)) and social factors (e.g. political boundaries and protected areas (PAs)). In order to store, manipulate, and then retrieve this data, a multivariable geo-database was developed. The design of this database was multipurpose. For one, it facilitated much of the geospatial processing involved for creating figures and later vulnerability indexes. Having the ability to filter based on a set of given queries (e.g. *Country, Biome, Power generation*) can be a powerful tool in revealing patterns in data that may not ordinarily appear in simple queries. Secondly, once created, this database will provide a one-stop online resource for people to map and compare dam impacts across the Amazon—similar to InfoAmazonia (http://www.infoamazonia.org/). Finally, and arguably most importantly, this database will address uncertainty and change – which are concerns plaguing the bridge of academic to political discourse in dam impacts (Fearnside 1985, 2001). For instance, when new and more accurate data is available for a certain dam (either in its planning stages or from an impact after its completion) the database can be updated to account for the modification.

Using the aforementioned geo-database, a series of figures and maps were produced that quantify different levels of factors on a per sub-basin scale that were not previously calculated within the Amazon. Details outlining the methodology and results are found in their respective chapters.

The design of this study is as follows: Chapter 1 sets the scope of the project by discussing the multi-conceptual concepts of space in the Amazon. Chapter 2 provides a thorough literature review on hydroelectric dams, connecting both global and Amazonian examples. Chapter 3 discusses economic drivers of mega-dams construction within the Amazon and also identifies case studies from other areas of the world. Chapter 4 examines the methods used within this project and reveals a multitude of current geophysical statistics per sub-basin. Chapter 5 reveals results of vulnerability studies and provides examples of dams organized by variables like country, sub-basins, power, and planned vs. existing. Chapter 6 concludes the piece by suggesting the importance of using powerful geo-spatial data to ask bigger social questions regarding human-environmental relationships.

This study suggests that social and environmental scales of the Amazon Basin offer a supremely unique example of a system on the edge of catastrophic change. On the one hand, the number of large dams planned for the Amazon basin would severely fracture fluvial, social and political systems; on the other, the proliferation of information on dam impacts in the Amazon may serve as powerful tool to fracture the fallacies that have historically been used to push mega-projects. Moreover, this study demonstrates how a multi-variable geo-spatial database can act as a useful tool in informed decision-making when attempting to consider multiple social and environmental factors. Given the rapid changes occurring in the Amazon, the results of this study have practical and urgent significance. Employing this type of analysis will better inform people of environmental disasters in the Amazon and support decision-making based on collective participation – not clandestine agendas.

Chapter 1: Setting the Scope The Amazon Fluvial Basin

The geographic focus of this paper deals with the Amazon fluvial Basin. Although there is a deluge of literature on "The Amazon" one must first understand the differences between these places, as they are spatially quite different. It is fundamental for this investigation to focus on the fluvial basin. In addition to this piece, which emphasizes the importance of evaluating impacts from the *basin perspective*, there are recent studies suggesting that a major change in attitude of freshwater biodiversity and ecosystem management will come from the recognition of the catchment as the focal management unit (Dudgeon et al. 2000).

1.1 Amazon Biome

Some studies refer to the Amazon biome as the "area covered predominantly by dense moist tropical forest, with relatively small inclusions of several other types of vegetation such as savannas, floodplain forests, grasslands, swamps, bamboos, and palm forests" (WWF). This biome has been cited at being between ~6.7 to 7.8 million km^2 (WWF and RAISG respectively). The methodologies and definitions for these limits are often complicated, and contain historical components. Within the literature, the most common are boundaries are: biophysical (hydrography, vegetation) and administrative (developmental/conservation/economics) examples: Amazônia legal (Brasil), Amazonía del Perú and Región Amazónica de Colombia. Amazonas is also the official name of a state in Venezuela, and also Brazil.

1.2 Brazilian Legal Amazon

Other studies are looking at the Brazilian Legal Amazon for example (Arima et al. 2005, Pfaff et al. 2007, Walker et al. 2009). The Legal Amazon which is ~5,000,000km^2 is an administrative region comprised of 9 states. The Legal Amazon was created in 1953 and slightly modified in 1977 (Fearnside 1997).

Dissecting and interpreting the nuances within these definitions is not in the scope of this paper. This study is focused on the fluvial basin, which covers Brazil, Bolivia, Peru, Ecuador, Colombia, and very small parts of Venezuela, Guyana, and forms a border with Suriname and French Guiana. Although a majority of the basin (approx. 69%) is located in Brazil, the basin envelops a large percentage of Bolivia and Peru at 66% and 60% of the area of these respective countries. Only four countries in South America are not associated with the Amazon basin.

1.3 Basin Stats and Scales in the Amazon

A drainage basin, catchment area, or watershed is the basin unit within which surface hydrology is analyzed (Finlayson et al., 2011). Drainage basins are generally classified as exoreic (with rivers discharging into the oceans), and endorehic (with the drainage terminating in the interior of a basin.

The Amazon drainage basin area of 6 x 10^6 km2 is the largest river basin in the world, covering about 5% of the land of Earth (Filizola & Guyot, 2004). The headwaters of the Amazon begin in the Peruvian Andes before flowing 3000km to the Atlantic Ocean. From the headwaters until its confluence with the Negro River (in Manaus) it is known as the Solimões River. After this confluence it is called the Amazon River.

The Amazon River's mean annual discharge is nearly 209 x 10^3 cubic meters (Latrubesse 2008), which contributes approximately 20% of annual global freshwater discharge to the ocean. Its sediment yield is on the order of 167 t/km^2 (Latrubesse 2008). The plume of the Amazon itself can reach 160km out to sea, which carries implications for ocean temperatures and wind patterns at a global level. The spatial expanse of the Amazon fluvial basin is so large that four of the ten largest rivers of the world (mega-rivers defined as mean annual discharge>$17x10^3m^3/s$) flow through the basin: Amazon, Madeira, Negro and Japura. In addition, 20 of the 34 largest tropical rivers in the world are also related to the Amazon Basin (Latrubesse 2008, 2012; Latrubesse et al., 2005).

Examples of the diversity within the tributaries are multifaceted. Take the Purus and Jurua rivers for example, located in the Southwestern Brazilian Amazon lowlands, which flow entirely in the equatorial climatic zone. The Madeira River which drains the Bolivian and Peruvian Andes also crosses the Brazilian Shield and delivers ~50% of total suspended load transported by the Amazon River (Filizola, 1999; Meade, 1994; Meade et al., 1979). Other systems also drain a variety of geologic-morphotectonic settings such as orogenic belts, platforms and plateaus, cratonic areas, lowlands and others. Rivers such as the Negro, Tapajós and Xingu are draining cratons under savanna and rainforest landscapes which characterized by low suspended sediment loads on the order of 10 to 20 Mt x yr^{-1} (Filizola, 1999; Latrubesse et al., 2005). -

1.4 Scales in The Amazon

The sediment load of the Amazon River can range from 600 to 1300 millions tons per year (Mt x yr^{-1}) (Filizola 1999; Filizola & Guyot, 2004; Meade et al., 1985; Mertes, Dunne, & Martinelli, 1996; Milliman&Meade, 1983). Almost all of the transport sediment (~90%) is due to local erosional processes with origins in the Andean tributaries (Filizola et al., 2011; Latrubesse et al., 2005; Meade, 1994, 2007).

It is important to emphasize the how issues of spatial scale will exacerbate impacts of hydroelectric dams within the Amazon basin with both local and global implication. For example, a decrease in sediment (explained in greater detail in subsequent chapters) will not only be devastating to the floodplain ecosystems, but will also decrease sediment load and nutrients arriving to the Atlantic Ocean. This change in sediment/nutrient flux has the potential to alter the Intertropical Convergence Zone (ITCZ) (Cook and Vizy, 2006). Moreover approximately eight trillion tons of water evaporates from the Amazon forests annually, which also plays an important role in global atmospheric circulation (IPCC 2007 / Solomon in EndNote). These same trees alone contain 90-140 billion tons of carbon (Soares-Filho 2006). To place this in perspective, this is approximately 9-14 decades of current global, annual, human-induced carbon emission (Canadell et al. 2007 taken from Nepstad et al 2008).

1.5 Geology and Geomorphology

With a spatial extent of 6,000,000 km^2 the geologic diversity of the Amazon fluvial basin is diverse. At a macro level however, three main features help to characterize the basin in both ancient and recent temporal scales. These three features are [1] the shields (Brazilian and Guiana), [2]The Andes, and [3]Lowlands.

The shields are large areas of exposed Precambrian crystalline rocks that can be older than 1 billion years old. In the case of shields within the fluvial basin the Brazilian and Guiana shield are an integral part of the geomorphology. The Brazilian Shield located primarily on the south side of the Amazon River is a pre-Cambrian geologic formation [expand here]. The Guiana shield covers the northeastern section of the fluvial basin and underlays French Guiana, Surinam, Guyana, a large portion of Venezuela, and some of southeastern Colombia. Before 12 MYA, these two shields were connected at the surface until the Amazon and its floodplain separated them (Hoorn et al. 1995).

Large tributaries of the Amazon such as the Xingu, Tapajós, and Negro drain these cratons, or platforms and are characterized by low suspended sediment loads of 10 to 20 Mt x yr^{-1} (Filizola, 1999; Latrubesse et al., 2005).

The Andean Mountain chain is the longest mountain range on earth, and supplies a vast amount of sediment, nutrients, and organic matter to the Amazon which contributes to a floodplain ecosystem that is one of the most productive on Earth (McClain et al. 2008, Barthem et al. 1997, Laraque et al. 2009, Aalto et al. 2002, Meade et al. 1985, Dunne et al. 1998). Over 90% of the transport sediment is associated with local erosional processes with origins in the Andean tributaries (Filizola et al., 2011; Latrubesse et al., 2005; Meade, 1994, 2007). In addition, there are tributaries like the Purus, Jurua, Jutai, and Javari that cross wide alluvial plains in the Brazilian lowlands.

Differences in elevation of these three distinct regions vary greatly with elevations in the Andes reaching over 6,000 meters. For example Huascarán in the Peruvian province of Yungay is 6,768 meters above sea level, the fourth highest peak in the Andes and only 5 km west of the Amazon fluvial basin. The tallest peak inside the basin is Yerupajá at 6,634 meters also located in Peru. Along the shields, today the

Guiana and Brazilian shields rarely hover over 1,000 meters in elevation. The low sedimentary regions that comprise a large amount of the fluvial basin usually do not rise about 300 meters above sea level.

The sediment load of the Amazon River can range from 600 to 1300 millions tons per year (Mt x yr $^{-1}$) (Filizola 1999; Filizola & Guyot, 2004; Meade et al., 1985; Mertes, Dunne, & Martinelli, 1996; Milliman&Meade, 1983). Almost all of the transport sediment (~90%) is due to local erosional processes with origins in the Andean tributaries (Filizola et al., 2011; Latrubesse et al., 2005; Meade, 1994, 2007). It is important to emphasize the how issues of spatial scale will exacerbate impacts of hydroelectric dams within the Amazon basin with both local and global implication. For example, a decrease in sediment (explained in greater detail in subsequent chapters) will not only be devastating to the floodplain ecosystems, but will also decrease sediment load and nutrients arriving to the Atlantic Ocean. This change in sediment/nutrient flux has the potential to alter the Intertropical Convergence Zone (ITCZ) (Cook and Vizy, 2006). Moreover approximately eight trillion tons of water evaporates from the Amazon forests annually, which also plays an important role in global atmospheric circulation (IPCC 2007 / Solomon in EndNote). These same trees alone contain 90-140 billion tons of carbon (Soares-Filho 2006). To place this in perspective, this is approximately 9-14 decades of current global, annual, human-induced carbon emission (Canadell et al. 2007 taken from Nepstad et al 2008).

1.6 Climate / Precipitation within the Basin

Temperature ranges across the basin hover around 24 to 26 degrees Celsius as the annual mean (GIWA) which takes into account annual averages below 24C in the mountainous regions being contrasted by temperatures above 26C in the lower/middle Amazon (Sioli 1975). Despite the relatively homogenous mean annual average temperatures, there are several climate types present in the basin including: Afi *(abundant rains throughout the year with total precipitation in driest months exceeding 60mm)* Ami *(relatively dry season, ith elevated total annual pluviometric rate)* and Awi *(relatively elevated annual pluviometric index, but also exhibits a clearly defined dry season)*. These were climatic classifications of Köppen and cited as (Day &Davis 1986) found in the GIWA.

With respect to rainfall there is variability between 1000 mm and 3600mm based on location. For example, it is more common to find even distribution towards the western extent of the basin, while the northern regions receive most of their rainfall in the middle of the year. (Salati et al. 1978, Salati & Vose 1984).

The Intertropical Convergence Zone (ITCZ) is a band around the earth near the equator where the southeast and northeast trade winds come together in a low-pressure zone. The ITCZ acts a key player in global circulatory systems. From the South American perspective, the ITCZ is located towards the northern tip of the continent during June-July, which provides more rain to the northern part of the basin. A second, but notable system is the Chaco low which is a low pressure system that brings the ITCZ south in January-February, the Chaco low is present in the middle part of the continent and provides rain to the Sothern part of the basin. These two systems, amongst other processes, assist in providing a fairly consistent rainfall within in the basin year round (Latrubesse 2008). A majority of this rainfall is provided by vapor leaving the Atlantic Ocean, which as it moves west across the basin is blocked by the Andes.

Chapter 2: Hydroelectric Dams

2.1 Global and Historical Perspectives

Dams have been built by humans for thousands of years to serve various needs like flood control, water supply, irrigation, recreation, navigation and generation of power (WCD, 2000). On a global scale, some studies suggest that over half (172 out of 292) of our large river systems are affected by dams, which includes eight of the most biogeographically diverse (Nilsson et al. 2005). Today, there are more than 45,000 dams over 15m high, capable of holding back >6500 km^3 of water or 15% of total annual runoff globally (Nilsson et al. 2005) with some studies estimating up to 50,000 (Berga et al. 2006). Due to finite lifespans and vast areas without sufficient studies, this type of quantification is loosely based. Some authors suggest there are 2.8 million impoundments larger than 0.1 ha (0.001km^2) worldwide and 16.7 million when including those larger than 0.01 ha (100m^2) (Lehner et al. 2011).

Although dam removal is an increasingly common in North America and Europe (most associated with cost prohibiting maintenance costs than ecological sentiment), the rate at which hydroelectric dams are being built today in the tropics is unprecedented (Brandt 2000). Considering that eight of the ten largest rivers in the world in terms of water discharge are located in the tropics, “mega-rivers” (Latrubesse 2008) are thus facing extreme pressures by dams. As these large fluvial systems act as conveyor belts for sediment-water transport dynamics at a global scale (Meybeck 2003) their health is also of global importance. Indeed it has been suggested that damming a river is a cataclysmic event in the life of a riverine ecosystem (Gup 1994 - Gup, T. "Dammed from here to eternity: dams and biological integrity." *Trout* 35 (1994): 14-20.)

The International Commission on Large Dams (ICOLD) is an international (non-governmental) organization founded in 1928, which now has more than 90 participating countries and 10,000 members (ICOLD). Designed to provide a "forum for the exchange of knowledge and experience in dam engineering" ICOLD has recently (as early as the late sixties) shifted some of its focus towards dam safety as many dams are reaching their age of deterioration. Among a host of publications and conferences that take place in many different countries, ICOLD also manages a dam registry of some 58,266 dams above 15 meters tall. Although recognized "as the best data basis on dams worldwide…despite all our efforts, some data are lacking" (ICOLD).

Interesting figures taken directly from ICOLD's website: http://www.icold-cigb.org/GB/World_register/general_synthesis.asp

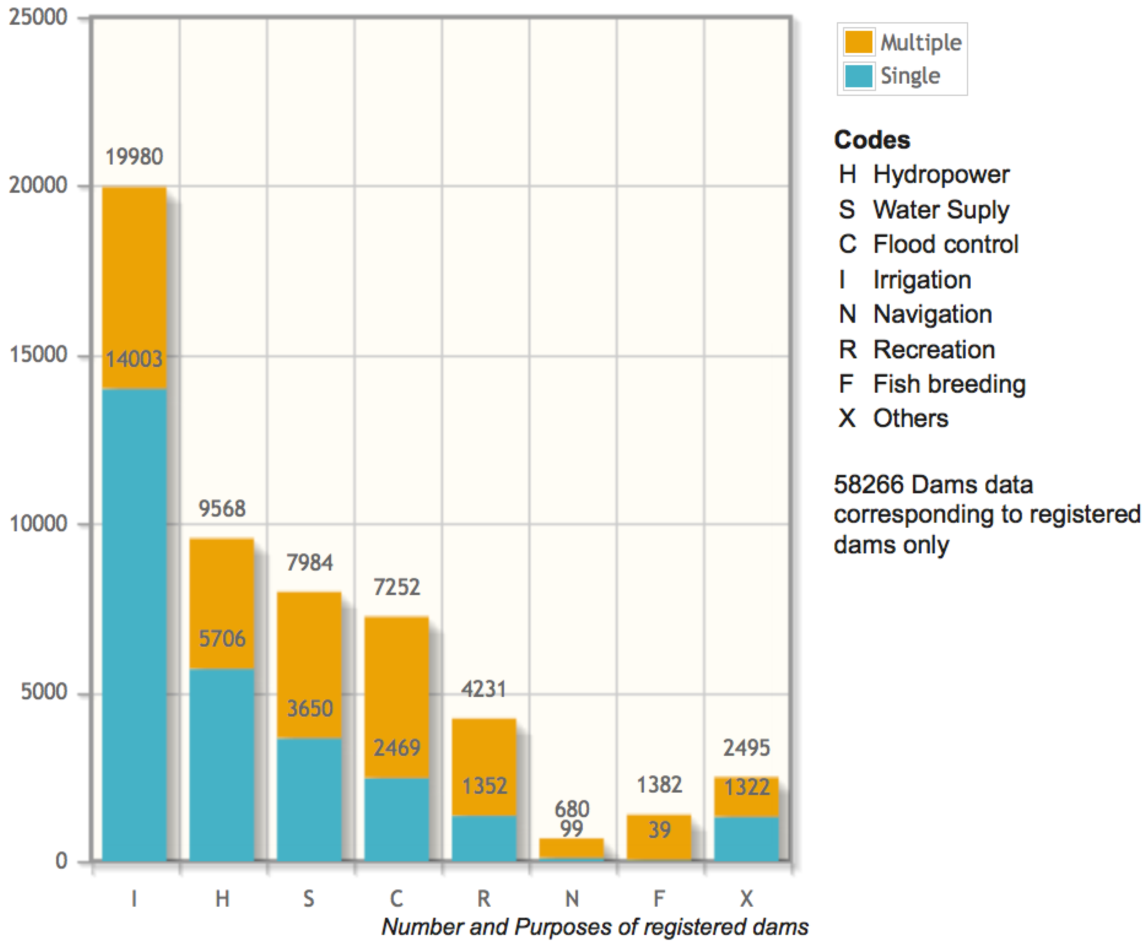
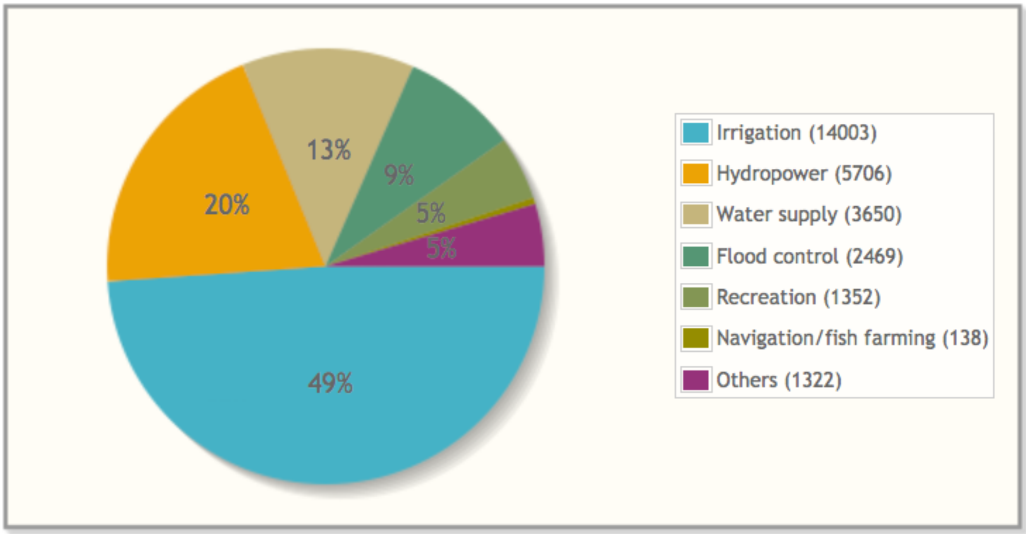


Figure 2: Types of Uses of Dams from ICOLD

Referenced dams can be broken in two main categories :

- single-purpose dams (28 640) or 49,2 % dams.
- multipurpose dams (9 812) or 16,8 % dams.

a) single - purpose dams :
The distribution for each purpose lead to the folowing results :



b) multipurposes dams :
The distribution for purposes lead to the following results :

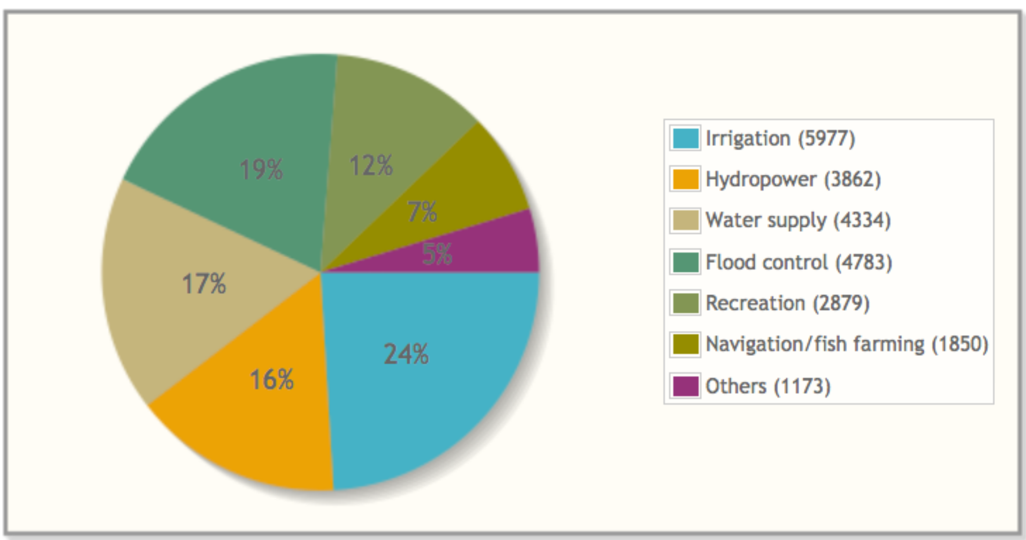


Figure 3: Dams as single and multipurpose – taken from ICOLD

Dam types

Earth dams predominate for some 63 % of all reported dams. This is of course the oldest type and there are traces or earth dams in the remains of the most ancient civilisations. Furthermore this type of dam can accommodate a wide range of different foundations. The world's second highest dam is Nurek dam in Tajikistan (300 m high).

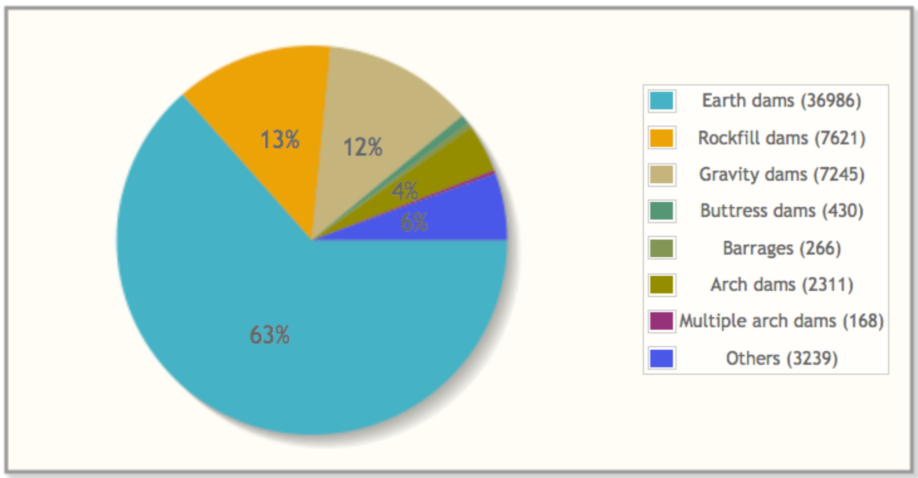


Figure 4: Dam types – taken from ICOLD

Dam impacts are multifaceted, complicated, and vary with time and space. Due to a range of geomorphological and land-use land change factors, no two dams have the same impacts, although they do share commonalities. Impacts can be felt on a host of different levels like: [1]environmental, [2]social, [3]economic, [4]political and in reality they most likely have overlapping impacts on all these levels. Moreover, these impacts vary depending on their location relative to the dam i.e. upstream or downstream.

One of the ways in which environmental dam impacts is divided have historically been divided is into [I]impacts by the reservoir and [II]impacts of the stream pattern. Through this dualistic lens, one can incorporate other levels as follows.

I. Environmental impacts imposed by dam reservoirs can include

- Upstream change from native river valley to reservoir
- Water quality issues
    - River temperatures
    - Turbidity
    - Dissolved gasses
- Sedimentation

II Environmental impacts imposed by dams on stream patterns can include

- Changes in flows (taking out peak flows which are extremely important for floodplain and ecological function)
- Local modifications of endangered and/or poorly understood ecosystems (Dunne, 2007; Fearnside, 2007, Tucci, 2007)
    - Downstream morphology
- Water temperature (usually lower than normal due to outflow being on the deep end of a reservoir and having less sunlight results in colder temperatures.
- Transportation
    - Fish
    - Cargo
- Sedimentation

The following section will briefly focus on examples of impacts that are of increasing importance within the Amazon Basin, such as:

- Gas emissions and water quality

- Sedimentation
- Geomorphological Effects
- Fish
- Social Costs

2.2 Gas emissions and water quality Issues

Some studies have looked at greenhouse gas emissions from reservoirs in an attempt to quantify their global significance. These studies depend on surface area, flux rates, contributing tributaries and of course geographic/geomorphological settings (see Rudd et al. 1993, Rosenberg et al. 1997). An especially dirty problem on the Madeira River and its tributaries is the amount of mercury released into the system, which during the 1980s gold rush was on the order of 100 t (Bastos et al., 2006 · Mercury in the environment and riverside population in the Madeira River Basin, Amazon, Brazil· Sci. Tot. Environ., 368 (2006), pp. 344–351). Mercury was used in the alluvial sediments to amalgamate gold particles (O. Malm, W.C. Pfeiffer, M.M. Souza Mercury pollution due to gold mining in the Madeira River basin, Amazon/Brazi Ambio, 19 (1990), pp. 11–15. Once again acknowledging the overlap in these *levels*, one finds that although the gold-mining was in the upper Madeira, human and fish populations in the lower Madeira (Porto Velho to the confluence) suffered high mercury levels more than a decade after the end of the gold rush (Bastos et al., 2006 - · W.R. Bastos, J.P.O. Gomes, R.C. Oliveira, R. Almeida, E.L. Nascimento, J.V.E. Bernardi, L.D. de Lacerda, E.G. da Silveira, W.C. Pfeiffer Mercury in the environment and riverside population in the Madeira River Basin, Amazon, Brazil Sci. Tot. Environ., 368 (2006), pp. 344–351). Some have suggested that velocity within the Madeira's tributaries will slow more that the main channel (· J. Molina CarpioHidrologia e sedimentos G. Switkes (Ed.), Águas Turvas: Alertas sobre as Conseqüências de Barrar o Maior Afluente do Amazonas, International Rivers, São Paulo, SP, Brazil (2008), pp. 50–93 http://www.internationalrivers.org/am%C3%A9rica-latina/os-rios-da-amaz%C3%B4nia/rio-madeira/%C3%A1guas-turvas-alertas-sobre-conseq%C3%BC%C3%AAncias-de-barrar-o- which has a host of complications.

For one, the slowing of water flow then creates anoxic conditions in tributaries, which create an environment for methylation of mercury, which alters this mercury toxic to humans (Fearneside 2014).

2.3 Deforestation and Effects on Gas Emissions

"Deforestation has direct and profound impacts on floodplains and their inhabitants. In essence, large-scale changes in flow are in inevitable result of deforestation. In turn, they encourage the construction of dams to protect against floods, which further alter the hydrological regime" (Dudgeon 2000)

Literature looking at deforestation near riparian zones usually focuses on surface runoff and increased river sediments, which in turn leads to habitat alterations. These can manifest themselves as shoreline erosion, smothering of littoral habitats, clogging river bottom or floodplain aggradation (Dudgeon et al. 2005). There is also a changing focus to look at dam impacts in tropical zones (Pringle et al. 2000, Anderson 2006, 2008, Fearnside 1995, 1997, 2000). Many of these studies focus on the enormous amounts of methane and carbon dioxide produced by hydroelectric dams. However due to complicated metrics of indirect and direct impacts on rates and pathways of decaying biomass, this quantification is difficult. This is a crucial next step in analyzing dam impacts as Fearnside points out "Hydroelectric emissions are the least well-understood of 'greenhouse' gas emissions from Amazonian deforestation (hydroelectric flooding is considered to be a form of deforestation)" (Fearnside 1995).

It is important to recognize that emissions related to greenhouse effect from reservoirs come in two major forms: [1]carbon dioxide and [2]methane and of the two, methane is much more potent in baiting the greenhouse effect. For example the Intergovernmental Panel for Climate Control (IPCC) suggests the average lifetime of methane in the atmosphere compared to carbon dioxide is 10.5 years versus 120 respectively, holding a constant-composition atmosphere (Isaken et al., 1992 pg. 56). In the case of carbon dioxide emissions by dams, the main culprit is the flooding and decaying of forests by the reservoir. Therefore the calculation of CO_2 is the carbon stock of forest (pre-dam) vs. carbon stock in reservoir once decay has reached equilibrium. Calculating methane, especially in the Amazon is difficult. For example, the várzea (white-water) floodplain has one of the world's major sources of atmospheric methane (Mooney et al., 1987, taken from Fearnside 1998). Emissions vary by source but include: open water, from macrophyte beds, above-water, and underwater decay of forest biomass. When calculating the methane emissions from underwater sources for example, one generally needs a place devoid of oxygen, high temperatures and high levels of nutrition – like reservoirs in the tropics. In the case of Tucurui, for example three-quarters of total green house gas emissions were methane (McCullyxxxiv). Complicating this calculation is the fact that methane is produced by ongoing biological processes independent of original forest biomass. In a rough estimation in 1990 it was concluded that hydroelectric reservoirs in Brazilian Amazonia emitted approximately .26 million tons of CH_4 gas and 38 million tons of CO_2 (Fearnside 1995).

In terms of famous cases in the Amazon, the Balbina reservoir on the Uatumã River (designed to supply the city of Manaus with power) presents a case of disastrous environmental costs associated with poor planning. In this example (see papers by Fearnside in the late 1900s for greater detail) one can understand the power/emissions balance calculations and some of their flaws.

When Junk & Mello 1987 calculated carbon emissions from Balblina they concluded it would be equivalent to 114 years of fossil-fuel burning they were assuming the installed capacity of 250 MW with an area of 1,650km^2. For starters, due to seasonal flows of the Uatumã, all turbines are in operation only a fraction of the year and in the dam was averaging some 112MW but with subsequent losses in transmission lines going to Manaus actually reduced average power being delivered to 109MW (Brazil, Eletronorte/Monasa/Enge-Rio 1976, taken from Fearnside 1995).. In 1989 taking into account the actual average capacity (112MW), the official reservoir area (2,360 km^2 at normal max operating level 50m asl), Fearside changed the number of years burning fossil fuel to 250 (Fearnside 1989). Worth noting in the above example, is that Balbina was located on a blackwater (high nutrient, shield draining) river – which means that carbon and methane budgets are very different than other tributaries in the Amazon.

Even in cases where reservoirs are very small, like the case of *run of the river* dams like Jirau/ Santo Antônio still contribute to greenhouse gas emissions via the carbon credit plan Clean Development Mechanism (CDM) of the Kyoto Protocol. As explained by Fearneside, the CDM approved the Jirau Project (May 17, 2013) the world's largest "renewable energy project" and the 6 million tons of CO_2 emitted (yearly) by purchasing countries of the carbon credit will actually represent a net impact on global warming (Fearenside 2014).

An important mention needs to be paid in terms of reducing these kinds risks associated with emissions prior to reservoirs filling. For example, dams in the American West (Glen Canyon, Hoover, etc) are not filling reservoirs with the biomass that the tropics contain. In an attempt to reduce the amount of decaying biomass in these reservoirs in the tropics, there have been meager attempts by companies (like Electronorte) to pre-clear land prior to reservoirs filling. In the case of Tucuri (on the Tapajos River) Electronorte "cleared less than a fifth of the 2,250 km2 of rainforest inundated by Tucuri and only a token 2 percent of the 3,150 km2 of forest inundated by Balbina " (McCully 38 ref number 29 Fearnside)

2.4 Sedimentation

Among numerous negative effects that hydroelectric dams can impose on river systems, sediment trapping is one of particular interests. Irrespective of a dams purpose "all dams trap sediment to some degree and most alter the flood peaks and seasonal distribution" (Kondolf 1997). By altering important natural sediment loads and flow regimes dams impose (depending of course on geomorphological settings) alterations in

[1]alluvial channel adjustments, [2]bed coarsening and loss of spawning gravels, [3]gravel replenishment below dams, [4]channel narrowing and fine sediment accumulation below dams and [5]coastal erosion (Kondolf 1997). Factors that contribute to the complexities associated with quantifying the amount of sediment trapped by dams include: native stream system characteristics geomorphologic constraints (geology, discharge, sediment inputs, sinks, etc), reservoir characteristics, and the type of dam that is impounding the reservoir. For example, dams without low-level outlets can trap up to 90 percent of incoming sediment (McCully 33). The sediment that arrives to the reservoirs then settles to the bottom and causes other issues [discussed later]. The water that does pass through the dam is then known as "clear water" or sediment poor flowing at controlled rates, which then acts differently and can be referred to as hungry water. In this case the downstream water (released from the dam) carries energy, which ordinarily would be carrying sediment, but due to the imposition of the dam, this water is sediment starved. In this case, the clear hungry water (in an attempt to supplement lost sediment load) can affect bed and bank erosion downstream. Usually this degradation of the riverbed just downstream of the dam will be aggradated further downstream than this process would have occurred under non-dam conditions (McCully 33, Kondolf 1997 - Kondolf, G. Mathias. "PROFILE: hungry water: effects of dams and gravel mining on river channels." *Environmental management* 21.4 (1997): 533-551.).

To put into perspective the compounding effect of sedimentation over time, consider the case of large reservoirs in the United States lose storage capacity at an average rate of around 0.2 percent per year, with regional variations ranging from 0.5

percent per year in the Pacific states to just 0.1 percent annually in the northeast. Likewise, in many major reservoirs in China – where soil erosion is a massive problem – lose capacity at an annual rate of 2.3 percent. (McCully, 107). In the Appalachians there is denudation on the order of 0.01 mm/yr (Leopold and other 1964 taken from Kondolf 1997) and the central Sierra Nevada's is around 0.1 mm/yr (Kondolf and Matthews 1993)(Kondolf and Matthews 1993), whereas New Zealand's South Alps are near 11 mm/yr (Griffiths and McSaveney 1983 taken from Kondolf 1997). The Aswan Dam on the Nile River in Egypt is a famous example of the dangers of erosion downstream of a dam (· S. Shalash Degradation of the River Nile, Parts 1 and 2 Water Power and Dam Construction, 35 (7) (1983), pp. 7–43 and 35(Kaimowitz), 56–58. 35, 37–43)

2.5 Geomorphological effects

Studies suggest more than 400,000 km^2 of land (an area the size of California) have been inundated by reservoirs worldwide (I.A. Shiklomanov, "World Fresh Water Resources" in P.H. Gleick 9ed.), *Water in Crisis: A guide to the World's Fresh Water Resources,* Oxford University Press, Oxford 1993, p. 14). Worth noting in this type of figure of course, is the quality of land that has been inundated by a reservoir. The first to flood and be lost to reservoirs includes floodplains, fertile farmlands, marshes, and forests that house impressive numbers of wildlife habitats. In fact many environmental movements over damming the American West (Edward Abbey) focus on this argument of loosing the best lands to dams. With lose of wildlife habitats in the floodplain, so too are fish habitats lost, or at best severely altered. For example, some argue that dams are responsible for the astonishing 1/5 of the world's freshwater fish now endangered or extinct (McCully7).

2.6: Fish

Figure 5- Photo of the fish passage at Santo Antônio near Porto Velho July 2014. Photo credit: Charles Wight

Along the Madeira River the impacts of dams on fish and fisheries is especially horrifying. For example, in a survey supported by the dam MRHC projects found ~800 species of fish in the Brazilian portion alone of the Madeira River – 40 of which were to new to science! (Lopes, 2011) (Madeira é rio com mais peixes do mundo. Novo levantamento diz que o rio amazônico supera todos os outros no mundo, com cerca de

800 espécies). Of particular concern in this case may be the grandes bagres (large migratory catfish) which ascended the Madeira each year for breeding in the Beni and Madre de Dios and are commercially important for this area. (Barthem and Gouldig 1997 and Barthem et al., 1991 – taken from Fearnside 2014). Although in other places fish ladders have been the design answer to dams obstructing migratory fish this approach may not be applicable in rivers like the Madeira. For example, fish ladders are common in the Northwest of the United States are designed primarily for salmon. In the case of the Madeira River on the other hand, the fish sleuths need to accommodate a range of migratotry species including giant catfish. The piracema (mass fish migration) from the Amazon to the headwaters of the Madeira was completely blocked in 2011 and partially blocked starting in 2012 (Fearnside 2014). Plants and animals aren't the only ones affected by dams, however, they do carry weight in conservation management issues (Abell et al. 2008) (Dudgeon 2000) (Dudgeon et al. 2005)

2.7 Social costs

Although the figures are hard to come by, some estimate the number of people flooded off their lands is along the order of 30 million – 60 million (McCully 8). These figures representing large discrepancies are complicated by indirect costs associated with spatial and temporal variables. To understand the difference in impacts as they change with time take for example communities severely affected over the duration of dam construction, like Altamira with the construction of Belo Monte on the Xingu River. Altamira is a city in the state of Pará which according to the Instituo Brasileiro de

Geografia e Estatistic had a population of 50,145 in 1991, had a population of 83,187 in 2014 (http://www.citypopulation.de/php/brazil-para.php?cityid=150060205). With tens of thousands of construction workers flooding the area there was marked increase in sex trafficking associated with dam construction workers (International Rivers http://www.internationalrivers.org/blogs/258/sex-trafficking-ringmaster-busted-on-belo-monte & Amazon Watch http://amazonwatch.org/news/2013/0307-human-trafficking-and-prostitution-scandal-threatens-belo-monte-dam). Unfortunately this situation is not unique to Altamira. Porto Velho and Jaci along the Madeira River have suffered a similar fate in recent years. At the peak of dam construction, which was sponsored by the governments Growth Acceleration Program (PAC), the town of Jaci, 20 km away from Jirau dam had 25,000 employees, which was over twice the predicted number of workers. This boost in workers took the town of 4,000 to 16,000 in 2009 and created some 68 points of (known) prostitution in Jaci (http://www.huffingtonpost.com/2014/03/13/amazon-river-devastates_n_4951671.html) Holding the spatial component constant at Altamira and changing temporal extent, just before dam completion (Feb 26th 2015) there were massive relocation efforts by Norte Energia to remove 2,000 families from the areas that will be flooded (http://amazoniareal.com.br/belo-monte-vai-remover-2-000-familias-em-dois-meses-em-altamira/).

Likewise, holding temporal components constant (April 2014), and looking at spatial variability both upstream and downstream of the Madeira River Hydroelectric Complex (MRHC), one also finds significant differences in impacts. For example the now infamous floods of March and April 2014 were captured very differently depending on spatial perspective i.e. Brazilian vs. Bolivian. In an article originally published in Folha de São Paulo, Brazilian President Dilma Rousseff argued using a unique fable that flooding in Bolivia (upstream of the MRHC) is not associated with the dams located downstream on the Madeira River in Brazilian territory: "é um absurdo atribuir às duas hidrelétricas a quantidade de água que vem pelo rio. E eu até uso a fábula do lobo e do cordeiro. O lobo [bebe água] na parte do cima do rio e diz ao cordeiro: 'você está sujando minha água'. O cordeiro respondeu: 'não estou, não. Eu estou abaixo de você no rio'. A mesma coisa é a Bolívia em relação ao Brasil. A Bolívia está acima do Brasil em relação à água", (Dilma; folha.uol). At the same time, on the Bolivian side of the dam complex some 30,000 families were experiencing unprecedented flooding which they believe was caused by the MRHC under construction (http://www.ipsnews.net/2014/04/brazilian-dams-accused-aggravating-floods-bolivia/) This distress prompted Bolivian President, Evo Morales to call for an in-depth investigation to assess whether the Brazilian hydropower plants are playing a role (IPSnews). The previous examples do not attempt to include any retribution towards economic or psychological trauma imposed by the dams.

Worldwide "reservoirs are estimated to have a combined storage capacity of as much as 10,000 km^3, equivalent to five times the volume of water in all the rivers in the world (Chao 1995). Acknowledging that inherently "water ignores political boundaries, evades institutional classification and eludes legal generalizations" (Wolf et al. 2003) many studies have set out to quantify basins at a risk on a global scale as well (Wolf 1998, Toset el al 2000, Gleditsch et al. 2006, Sadoff et al. 2002 etc.) These studies have carved out an important research niche as more than 200 river systems are shared by two or more countries (Wollebaek et al. 2000) with some who suggest there are 263 international rivers draining 45% of the Earth's land surface (Dudgeon et al. 2005). This leads some to suggest that there may not be a substantial number of water bodies that have not been irreversibly altered from their original state by humans (Leveque &Balian, 2005 taken from Dudgeon et al. 2005).

It is noteworthy that some of the leading scholarly articles on dam impacts at a basin scale, like the *International waters: identifying basins at risk (Wolf et al. 2003)* do not identify the Amazon basin as a basin with the potential for political stresses in the coming five to ten years (Wolf et al. 2003). In fact, La Plata was the only basin in South America identified in this study. Basins on the list were: Ganges-Brahmaputra, Han, Incomati, Kunene, Kura-Araks, Lake Chad, Lempa, Limpopo, Mekong, Ob (Ertis), Okavango, Orange, Salween, Senegal, Tumen and Zambezi. (Wolf et. al. 2003).

Some of the complications in current literature of dam impacts as mentioned by Wolf et al. include: Loose definitions, exclusions of cooperative events, lack of consideration of spatial variability, and case studies selected only from the "hottest" basins. (Wolf et al. 2003). Wolf's research team has created a database called the Transboundary Freshwater Dispute Database (TFDD) with Oregon State University Department of Geosciences, in collaboration with the Northwest Alliance for Computational Science and Engineering. Within the database which includes: 263 international watersheds, 400 water-related treaties, and 39 US interstate compacts, only 224 relate to South America, and of those only 17 relate to the Amazon.

In terms of an Integrated and Sustainable Management of Transboundary Water Resources (ISMTWR) for the Amazon, the major strategic alliance was the *Treaty for Amazonian Cooperation* 1978 between Bolivia, Brazil, Colombia, Ecuador, Guyana, Peru, Suriname and Venezuela. (41 page document found: http://www.oas.org/OSDE/Events/english/PastEvents/Salvador_Bahia/Documents/Amazonannexes.pdf) Within the document no explicit mention of hydroelectric dams was found. Article V however, does state "Contracting Parties [aforementioned group of countries in the contract] shall make efforts aimed at achieving rational utilization of hydro resources" (OSDE).

Similar to early work in fluvial geomorphology, a large body of academic literature on dams was produced in the northern hemisphere (AmericanRivers.org, Graf 1999, Graf 2006 Graf, W.L. (2006). McCully, Baxter 1977, Downstream hydrologic and geomorphic effects of large dams on American rivers. *Geomorphology*, 79, 336-360.) , . There have been many studies of dam fragmentation in North America and the northern hemisphere, which suggested 77% of total water discharge of the 139 largest river systems in North America (north of Mexico), Europe, and the former Soviet Union is "strongly or moderately affected by fragmentation of the river channels by dams" (Dynesius and Nilsson 1994). Examples within the United States alone suggest there are 75,000 dams in the continental United States capable of storing water equal in volume to one year's mean runoff (Graf 1999). There are estimates that suggest that the water impounded by dams in the Northern Hemisphere is so large that it has caused measurable geodynamic changes in the Earth's rotation and gravitation field (Chao 1995). In fact, an article in Business Insider was published in 2010 to try to discuss whether the Three Gorges Dam in China once filled could change the rotation of the earth. The three gorges dam, the larges dam in the world with a power capacity of 22,500MW raises water level 175 meters above sea-level and creates a reservoir 660 km in length by 1.12 km (on average) in width which means the water behind the dam could weigh 39 trillion kilograms (Cleveland 2010). The resultant conclusion in this piece was that indeed it is possible that this mass could change the length of day by only 0.06 microseconds, claiming, "although most shifts are too small to be measured, they can be calculated" (http://www.businessinsider.com/chinas-three-gorges-dam-really-will-slow-the-earths-rotation-2010-6#ixzz2gLFLVmuJ)

In the same way that dam building and research came first to the northern hemisphere, so too this fad first faded and by the late 90's pressures by activists and economics had all but ended the building of big dams in Northern countries (McCully 2001 xxi, AmericanRivers.org, Grant, 2003, Hickey, 2013, Yardley 2011). This is not the same for South America. Indeed, others have pointed out that "in the tropics, where research funds are few, often the only scientific study of a river system has been done to find where best to dam it" (A.P. Covich, 'Water and Ecosystems', in P.H. Gleick (ed.), Water in Crisis: A guide to the World's Fresh Water Resources, Oxford University Press, Oxford 1993, p. 41; B.L. Johnson et al. 'Past, Present and Future Concepts in Large River Ecology', BioScience, Vol. 45,No.3 March 1995, p. 134 – taken from McCully pg. 31)

Examples within the United States alone suggest there are 75,000 dams in the continental United States capable of storing water equal in volume to one year's mean runoff (Graf 1999).

2.8 Run of the river vs. "conventional"

Large dams are usually defined by ICOLD as a dam measuring 15 meters or more from foundation to crest. Dams of 10-15 meters may be defined as large dams by ICOLD if they meet the following requirements: crest length 500 meters or more, reservoir capacity at least 1 million cubic meters, maximum flood discharge at least 2,000 m3/s, 'specially difficult foundation problems' or 'unusual design'. ICOLD is the International Commission on Large dams – a Paris based dam non-governmental industry association

This list below includes some of the biggest dams in the world, like Three Gorges Dam in China that is rated at 22,500MW of installed power

Dam	*Installed Capacity*	*Country*
Itapu	14,000MW	Paraguay/Brazil
Baihetan	14,000MW	China
Xiluodu	13,860MW	China
Belo Monte	12000 MW	Brazil
Guri	10,200 MW -	Venezuela
Tucuruí	8,370MW	Brazil
Santo Antônio	3,150 MW*	Brazil

Table 1: Numbers from ICOLD Classification by Installed Capacity with Energy

**Number from personal communication with engineer from Santo Antônio Energia

2. 9 Conventional Hydroelectric Power Dams (reservoir impounding)

Figure 6 Photo of Mansfield dam in Austin Texas. Installed capacity of 102MW for comparison. Photo credit: Charles Wight

Power of conventional hydroelectric dams is produced by potential energy of dammed water which drives a water turbine and a generator. Among other factors driving power are the volume of water and the difference in height between of source and water outflow - the difference in height is called the head or hydraulic head. For a hydroelectric dam, the head equals the vertical distance between the elevation of the surface of a reservoir and the surface of the river where turbined water re-enters downstream. (Glossary, Silenced Rivers).

Some estimates states "hydropower generates a fifth of the world's electricity to supply water for agriculture, industries and households, to control flooding and to assist river navigation by producing regular flows and drowning rapids" (ch.1 – Silenced Rivers; McCully 2001)

2.10 Run of the River Dams

Figure 7 Santo Antônio near Porto Velho, July 2014. Photo credit: Charles Wight

Hydroelectric generation which raises upstream water level but creates only a small reservoir and cannot effectively regulate downstream flows are known as Run of the River dams (Glossary Silenced Rivers). Run of the River dams only create small head ponds and therefore cannot regulate downstream flow as conventional dams do. Head pond refers to the reservoir behind RUN-OF- RIVER dams. Although they may have less severe consequences "run-of-river dams are far from environmentally benign" (McCully, 12)

2.11 Appendix materials:

Although he tends to carry a more ecological focus with respect to dam impacts, Philip Fearnside (INPA) has written extensively on issues with the (Brazilian) Amazon:

Greenhouse gas considerations: Fearnside (1995) and case specific Balbina dams – Fearnside (1989) and Tucuri Dam (2001)

More on dams and association with greenhouse gases: Rosa et al 1996, Fearnside 1995, Louis et al. 2000, Fearnside 2000, Fearnside 2004 and, the World Commission on Dams 2000.

With respect to evaluating river fragmentation and flow at large scales (Mekong River Basin) (Grill et. al. 2014) works within the framework of dam effects on hydrological and ecosystem integrity "which reach beyond the scales addressed by typical environmental impact assessment" (Grill et. al 2014). Citing issues associated with environmental impact assessments for individual dams as focused small scaled, isolated impact, this study calls for a more 'holistic river mindset' for river basin development and management plans. Parlaying this mindset with newly available data resource and software tools, the hope is to reveal cumulative effect of dams on the entire river system, thus helping to identify important linkages and critical thresholds (Lehner et al., 2011).

Effects on hydrological connectivity are numerous, (Vorosmarty et al., 2010) (Fullerton et al., 2010) (Pringle et al. 2011) etc however most of these are examining connectivity of fluvial systems through an ecological lens. Examples: Flow regulation (Lehner et al., 2011) and Sediment delivery (Syvitski et al., 2009)

[Evaluating dam impacts in more holistic analysis at small scale, Costa Rica – hydropower consumption, ecological consequences, and conservation strategies (Anderson et al. 2006) is a good piece.]

Speaking more directly to connectivity and interactions between systems of the Andes and the Amazon there are a range of biogeographic and ecological perspectives. Considering their long marriage it's remarkable "the Andes constitute only 13% of the Amazon River basin, they are the predominant source of sediments and mineral nutrients to the river's main stem, and Andean tributaries from productive corridors extending across the vast Amazonian lowlands" (McClain et al. 2008)

With respect to the Andes, Herzog el al. cite that "regionally, hydropower dams generate ~54% of electricity, although reliance on hydropower varies by country" (Herzog et al. 2011). Examples from Ecuador indicate ~45% of electricity comes from hydropower, largely generated by a single 1075MW plant on the Paute River (Consejo Nacional de Electricidad del Ecuador) (Herzog et al 2011). Ecuador has exploited some 15% of its estimated hydropower potential (Pelaez-Samaniego 2007)

For purposes of this study only one dam in Colombia falls within the fluvial basin, however, as a country, "Colombia leads the Andean region in hydropower development, where approximately 50 large (>15m high) and many smaller dams generate ~80% of their electricity"(World Commission on Dams 2000; Diez and Burbano 2006; P. Petry, pers. Comm, taken from Herzog et al. 2011, pg. 330). In Peru ~70% of electricity is generated by hydropower whereas in Bolivia the number is closer to ~40% (Herzog et al 2011). Brazil also has a vested interest in hydropower from the Andes (Bolivia and Peru specifically) with the intent of this energy generated to be exported to Brazil (Herzog et al. 2011, 330). Also see table from Herzog 2011 in Appendix.

Chapter 3: Economic Drivers – Who is building?

3.1 Large Dams

Large dams have been controversial on several fronts including substantial financial costs (World Bank 1996, World Commission on Dams, 2000). The World Commission on Dams (WCD) for example, reported that for large hydropower dams "average [hydropower] generation in the first year of commercial operation is 80% of the targeted value" (World Commission on Dams 2000 pg. 30). The economies of scale for large dam projects is so large today that even large economies (i.e. China) could see negative economic complications if risks associated with these project are not well managed (Salazar 2000). Furthermore, some studies suggest "such enormous sums of money ride on the success of megaprojects that company balance sheets and even government balance-of-payment accounts can be affected for years by the outcomes" (Merrow et al 1988). In a dataset of 81 large dam the WCD found on average construction costs overran by a massive 56 percent – these poor cost overruns were actually found to be worse in South and Central Asia, where they averaged 138 and 108 per cent respectively (WCD, McCully 25).

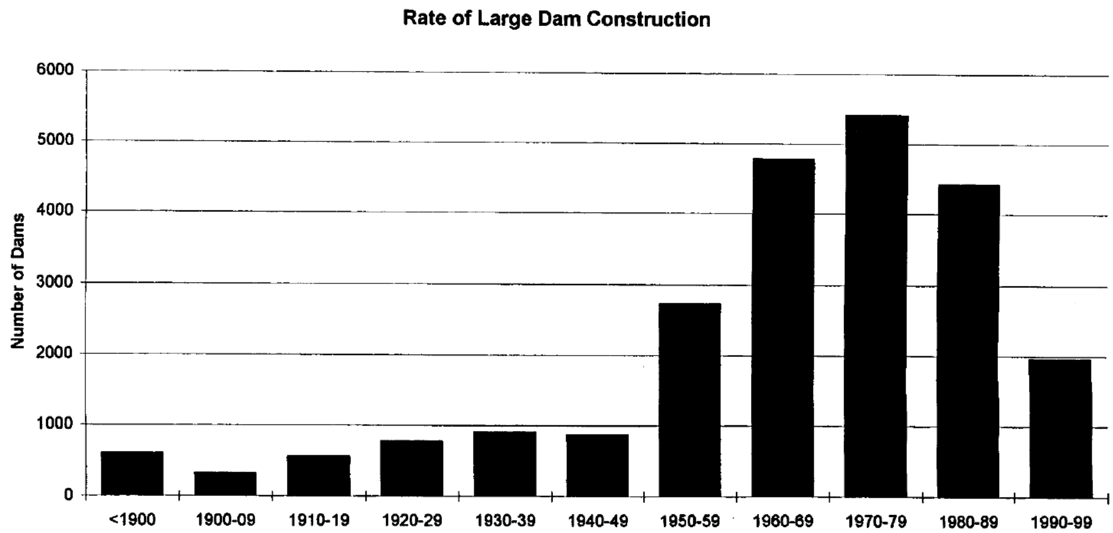


Figure 2. Rate of construction of large dams in the twentieth century (data from ICOLD 1998).

Figure 9: Taken directly from Rosenberg et al. 2000 BioScience

These economic issues become more complicated when the plans of projects grow over time, and there is a host of literature on the psychological and political implications of mega-construction projects. This is an especially pertinent point on the Brazilian dam scene as some of the plans dams that are under construction (ex: Belo Monte) actually transcend political parties. For more on psychology of delusion and deception in large hydropower dam planning see planning fallacy (D. Kahneman, A. Tversky 1979, Sovacool and Cooper 2013, Kahneman 2013). This is in part what leads politicians to chasing funds for big expensive projects in their districts in order to win more votes, to be elected the next time, to advance the same project etc. (McCully, xvi)

Similar to the WCD cost overrun analysis, a study in Ontario took data of several hundred North American dams and showed on average cost of operation rise dramatically after 25-35 years due to increasing needs for repair (McCully 126). This point is especially pertinent in rivers of high sediment load where turbines are under constant threat of being clogged by sediment. For example, on Santo Antônio dam on the Madeira River, they have to have dredging crews dredging sediment twice a day upstream and downstream of the dam due to the abundance of sediment (Personal communication with engineer from Santo Antônio Energia).

Tides are changing though and the huge money that's needed for these mega projects is becoming harder to obtain – or at least from single point sources. For example, even the World Bank, who used to be one of the biggest funders of the international dam industry, has already cut half the number of dams that it funded during peak levels (McCully xvii). Worth noting of course, is that this drop of funding may have do with the fact that there are not as many dam projects today as there were during peak levels of dam construction. Nonetheless the negative criticisms dam builders now face (and exacerbated with social media) have given the World Bank a good excuse to slow the cash flow. Some studies show that even multilateral development banks and national development agencies are also slowing their funding for mega dam projects (McCully xvii).

Once again parlaying the difference in comparisons of South America vs. North America/European dam construction, one must consider issues of scale, and specifically scale of corruption. For example, it may well be true that in the neotropics, dam construction is primarily motivated by growing demands for electricity, and many new dams are for hydropower production (Fearnside 1995; Pringle et al., 2000; Anderson et al., 2006). Growth in per capita electricity consumption in tropical, developing countries is expected to double over the period 2005–2025, as emerging economies expand, human populations grow, and access to electricity improves (Goldemberg, 2000; EIA, 2005). Moreover, the tropics are where much of the world's remaining hydropower potential is still remaining (McCully 2001). These are reasonable political vantage points that make sense for dam construction.

However, here lies the one of the principal arguments opposing mega dam construction in the Amazon: If it is the case [as identified in section_____] that dam construction has historically always run over cost and currently funding is disappearing, and devastated social and ecological structures, (both of these factors being exacerbated in the Amazon for aforementioned reasons) –how is it the case that plans to place another 200 dams in the Amazon is going through in 2015? One answer, which has been swirling in academic/activist debates for decades, and has very recently been leaking onto social media, is the *Mounting Evidence of Corruption in the Brazilian Dam Industry (Millikan and Poirier 2015, International Rivers)*

In March of 2015, millions of citizens throughout Brazil too to protesting "rampant corruption, erroneous economic policies and rollbacks of social benefits" (Millikan and Poirier 2015) in the streets calling for the impeachment of President Dilma Rousseff who is linked to the corruption scandal of Petrobras. Within this riveting report:

"On March 8th, news broke that Dalton Avancini, president of the civil construction empire Camargo Correa, would confirm in testimony to Federal Police and Public Prosecutors that Camargo Correa paid R$100 million (US$30 million) in bribes to two political parties – President Dilma Rousseff's Workers' Party (PT) and it's main

ally in the ruling coalition, PMDB – in exchange for construction contracts for the Belo Monte Dam. "(International Rivers blog260)

Mr. Avancini reported "each political party received 1% of the value of Camargo Correa's 16% share in the Belo Monte construction consortium" (International Rivers blog260). In a piece by Claudio Angelo wrote that this news "irrefutably demonstrates how "huge projects that violate environmental legislation, economic order, human rights and good sense, are designed to generate money (for corruption), not energy" (International Rivers blog260 / http://scienceblogs.com.br/curupira/2015/03/o-impacto-ambiental-da-lista-de-janot/)

3.2: Economics

In an excellent article published recently in Energy Policy, *Should we build more large dams? The actual costs of hydropower megaproject development* found overwhelming evidence of biased budgets below actual costs of large hydropower dams – even when discounting for inflation substantial debt servicing, environmental and social costs (Ansar et al. 2014). Using data found in the World Commission of Dams (WCD), Asian Development Bank, Word Bank, U.S. Corps of Engineers, and Tennessee Valley Authority. Among many of the discoveries within this piece is the relationship between size and cost overrun which is an argument with historical opposition.

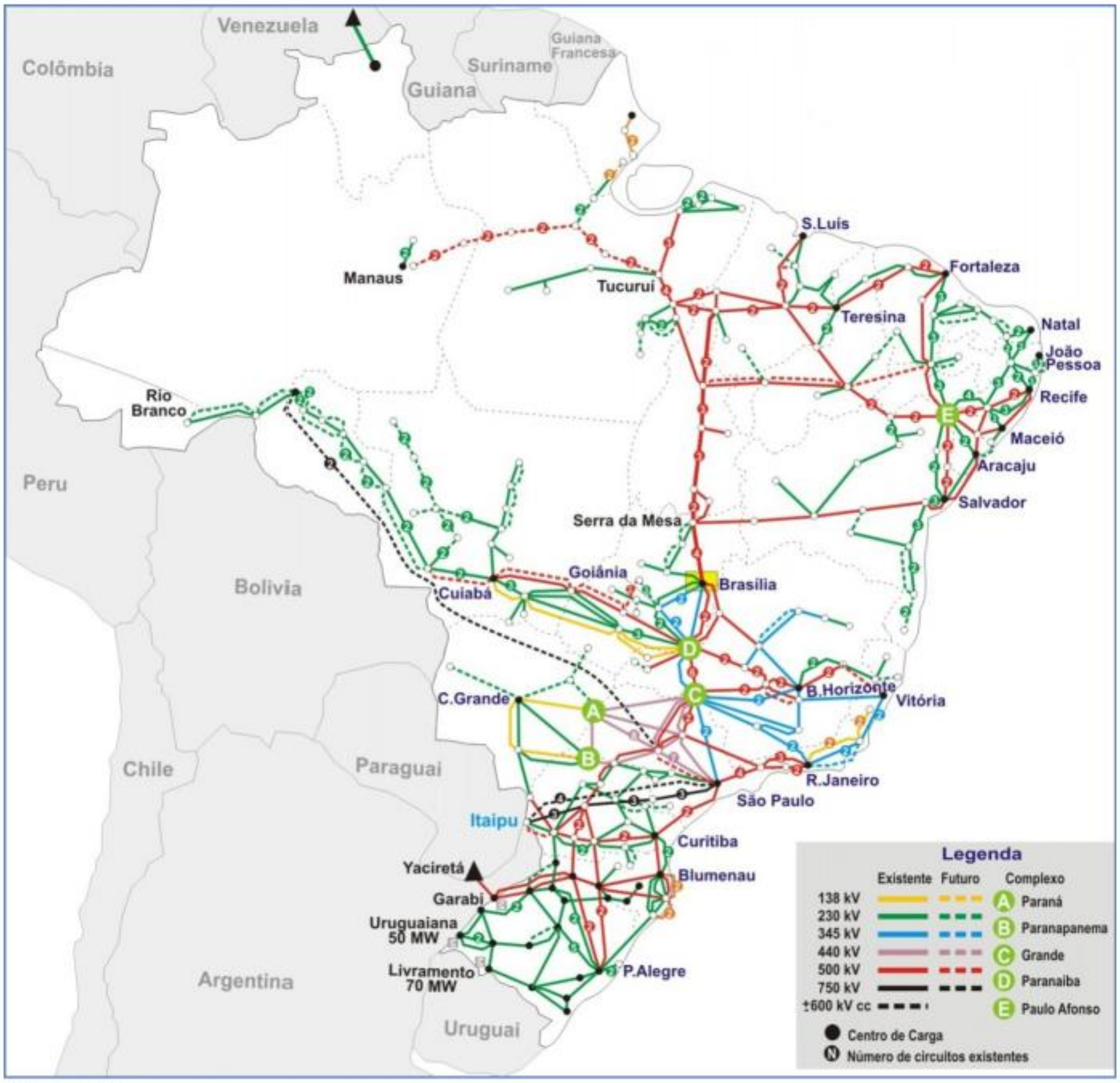
"a preliminary univariate analysis, which makes no attempts to take into account any covariates, shows that increase in the scale of a dam, e.g., measured as height of the dam wall, increases the absolute investment required exponentially, e.g., a 100m high dam wall is four time more costly than a 50m wall….even stronger relationship can be seen between installed capacity MW and actual cost" (Ansar et al. 2014)

Analyzing cost overruns of large hydroelectric dams several observations have been made (Ansar et al. 2014) and condensed as follows to synthesize:

1. Three out of every four large dams suffered a cost overrun in constant local currency terms
2. Actual cost were on average 96% higher than estimated costs
3. Graphing dams' cost overruns reveals a fat tail – the actual costs more than double for 2 out of every 10 large dams and more than triple for 1 out of every 10 dams. This suggests that planner have difficulty in computing probability of events that happen far into the future
4. Large dams built in every region of the world suffer systematic cost overruns. However dams in North America have considerably lower cost overrun.
5. Typical forecasted benefit-to-cost ratio was 1.4 – planners expected the net present benefits to exceed the net present costs by about 40%
6. Testing whether or not forecasting errors differed by intent of projects (ie hydropower vs. irrigation vs. multipurpose) or wall type (earthfill, rockfill, concrete, etc.) and found "irrespective of project or wall type, the probability distribution from the broader reference class applies"
7. Whether or not cost estimates have become more accurate over time? Statistical analysis suggest irrespective of the year or decade a dam was built there are no significant differences in forecasting errors. "Forecasts of large dams today are likely to be as wrong as they were between 1934 and 2007"

3.3: Small dams vs. big dams.

From an economical standpoint alone, small dams are cheaper and less risky for investors whether they're paid for publicly or privately. A counter argument to the pro-dam/economic stimulus argument can easily be made that with a smaller dam there is more likelihood that benefits association with construction and operation is felt by local communities instead of outsiders (McCully 25). In fact, this points to one of the historical precedence set by dam construction – namely to provide power for industrial extractive techniques. In the case of Brazil, for example, there is a price disparity between purchase price of electricity of residential vs. industry. Many of the small dam arguments are befitting for the countries within the Amazon basin, as many of the proposed dam sites do not yet have adequate infrastructure to support construction and connection to the grid. This is in contrast to the Hoover dam project, for example, in which dam construction took advantage of the many federal projects that were injecting money into infrastructure projects. For example, in the Amazon Basin, many of the megadam projects' energies are actually being transmitted down to power hungry Southeast of the country like Sao Paulo and Rio de Janeiro requiring huge transmission lines to cut across the country (which also carry environmental implications). The idea of small dams could actually provide electricity to small villages that are not connected to the national grid, i.e. communities whose rivers are being dammed.



Fonte: ONS

Figura 4 – Diagrama do Sistema Interligado Nacional

Figure 10 taken directly from Renewable Energy Latin American (RELA):

An additional benefit of small dams for the social impacts is that if one does need to displace people due to reservoir construction, it will be fewer people. To that end, if there is a catastrophe and the dam breaks, a small dam will put fewer people at risk.

Chapter 4 Methods

4.1: Creating *accurate* sets of major sub-basins

4.1.1: Deriving sub-basins and Issues of uncertainty:

As stated by the USGS, “Typically river network products derived from digital elevation surfaces are susceptible to various errors, foremost in flat regions without well-defined relief” (Quality assessment > http://hydrosheds.cr.usgs.gov/quality.php>)

Although several databases contain sub-basins of the Amazon fluvial system, many of these datasets contain gross errors when analyzed at different scales. For example, the Large-Scale Biosphere-Atmosphere Experiment in Amazonia (LBA) contains datasets for “intensive scientific investigation of the tropical rainforest of Brazil and portions of adjacent countries” (http://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=1086) These datasets like LBA-ECO CD-06 Amazon River Basin Land and Stream Drainage Direction Maps use ~500M gridded land and stream drainage to provide maps which result from a “topography-independent” analysis method by (Mayogra et a., 2005) which used vector river network from the Digital Chart of the World (DCW, Danko, 1992). However, upon close inspection, these maps contain questionable geometries, and when compared to newer datasets (discussed in upcoming section) they do not seem to be as reliable.

For this investigation, the author chose to use the HydroSHEDS (BAS) Drainage basins watershed boundaries at 15s resolution. Credits to this dataset go to the World Wildlife Fund (WWF) and (Lehner, B., Grill G. 2013). HydroSHEDS (Hydrological data and maps based on SHuttle Elevation Derivatives at multiple Scales) claims to provide "hydrographic information in a consistent and comprehensive format for regional and global-scale applications" (HydroSHEDS). They offer a host of geo-referenced datasets including stream networks, watershed boundaries, drainage directions, and ancillary data layers like flow accumulations, distances, and river topology (HydroSHEDS). http://hydrosheds.cr.usgs.gov/overview.php HydroSHEDS is derived from elevation data of the Shuttle Radar Topography Mission (SRTM) at 3 arc seconds resolution. The final products are available in resolutions from 3 arc-seconds (approximately 90 meters at the equator) to 5 minute (approximately 10km at the equator). This product was not designed to reach accuracy of high-resolution river networks like those depicted in existing maps or remote sensing imagery (HydroSHEDS/USGS>quality assessment) Users are encouraged to further improve HydroSHEDS in this respect. To that end, these datasets work well on the continental scale, because particular basins are (at this point) are being treated (as much as possible) equal. This of course can be improved in future investigations. After all, the quality of HydroSHEDS depends on the quality and characteristics of the SRTM-based digital elevation model (DEM) (http://hydrosheds.cr.usgs.gov/quality.php) these can be influenced by vegetation among other surface effects like roughness, wetness, open water (Freeman, 1996) etc.

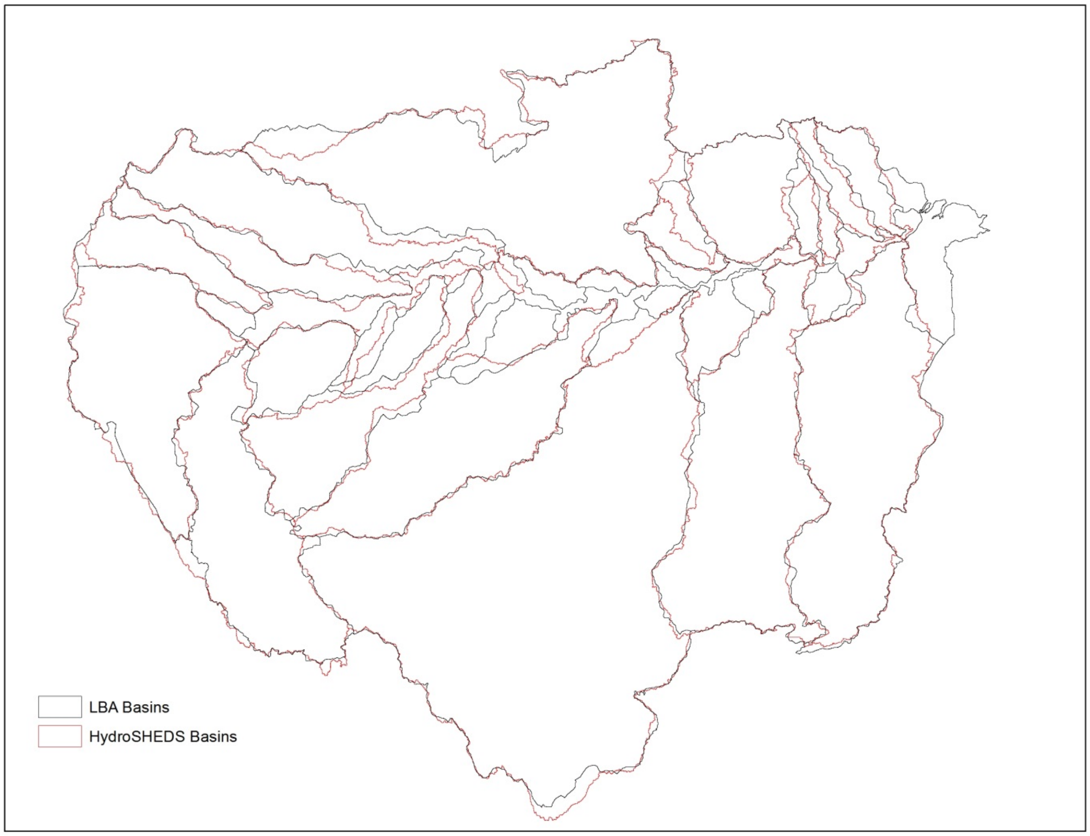


Figure 11: LBA vs. HydroSHEDS overlay

Once downloaded, the South American dataset was brought into ArcGIS 10.1 for quality control before using the data in other GIS programs. The projected coordinate system is South America Albers Equal Area Conic. The conic projection distorts scale and distance except along standard parallels, "areas are proportional and directions are true in limited areas, this projection is typical in large countries with a larger east-west than north-south extent, like the United States" (Dana, Geographers Craft). The Albers Equal-Area projection is useful for a customized projection for a particular region, in this case, South America. Considering the geographic shape of the basin, and the availability of this projection within the suite of GIS programs I was using, I chose this projection.

4.1.2 Smoothing

In order to retain higher cartographic appeal at very large scale, the tool *Smooth Polygon* was used to smooth the rough edges that were the result of the HydroSHEDS processing. After experimenting with different smoothing tolerances (30, 90, 100, 500, 900 and 9000 meters) 900 meters was chosen as the tolerance that retained shape at continental scales : 1:15,000,000 and also detailed scales for other purposes: 1:60,000.

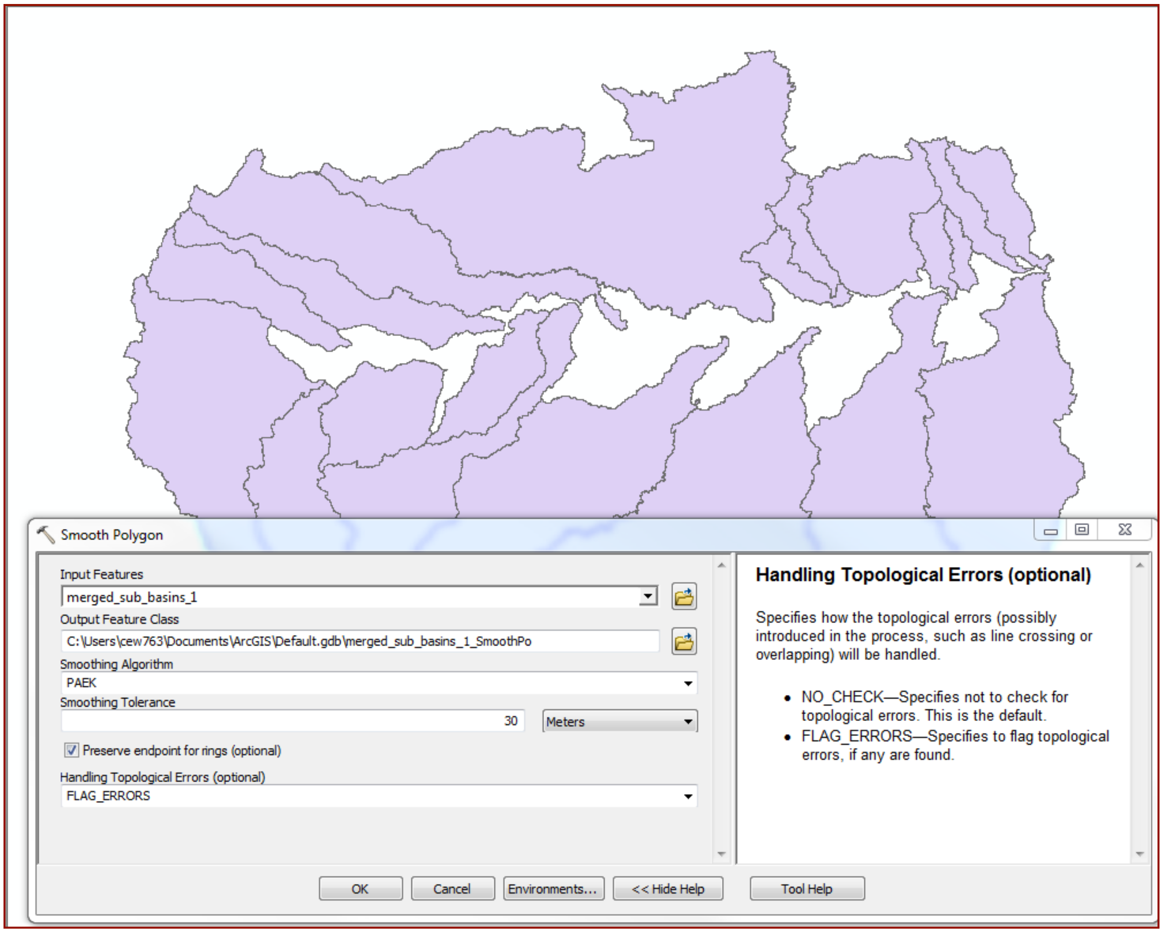


Figure 12 Smoothing Polygon Function for more realistic look of basin edges

In red is the 900m smoothing, and black is 90m smoothing tolerance at the border of the Negro and Caqueta sub basins. Spatial scale in this diagram is 1:60,000.

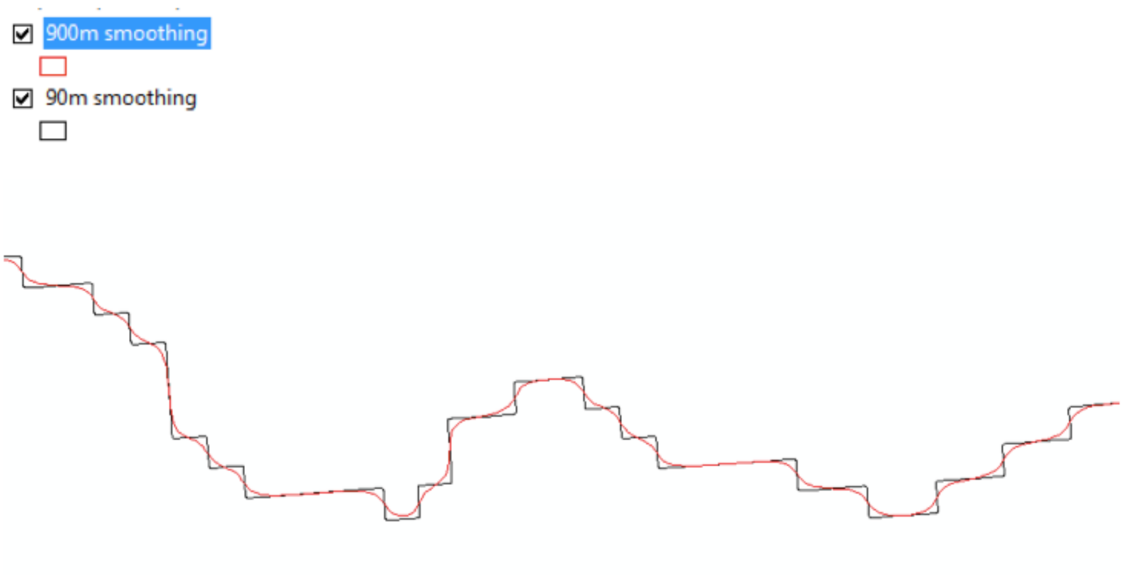


Figure 13: 900 meters vs 90 meters smoothing overlay

4.2.1:Land Cover per basin

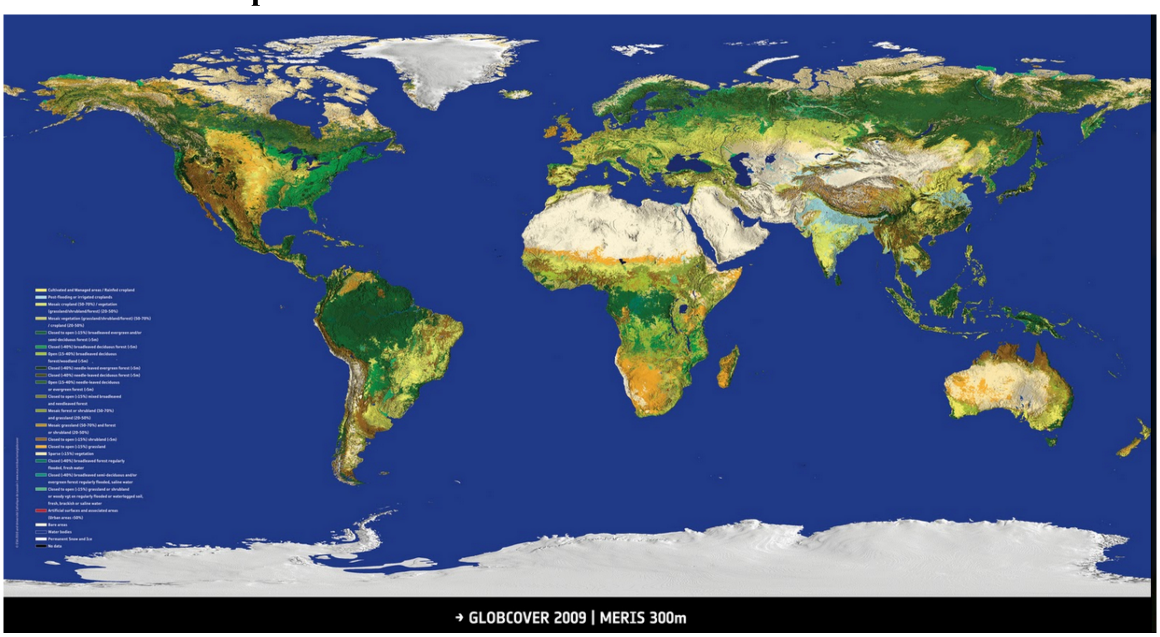


Figure 14: Globcover2009 300m global LULC

The GlobCover project was developed by the European Space Agency (ESA) in 2005 and by 2008 had provided the international community with the first 300m global land cover map for 2005. Employing feedback from organizations like JRC[1], EEA[2], FAO[3], UNEP[4], GOFC-GOLD[5] and IGBP[6], the ESA[7] and the Université catholique de Louvain (UCL) produced the GlobCover 2009 land cover map. The final product contains three deliverables: [1]*Bimontly surface reflectance mosaics* (6 products a year), [2]*Annual surface reflectance mosaic* (1 product per year), and [3]Land cover map (1 product a year). This paper will examine the third deliverable, the GlobCover2009 land cover map. Released in December 2010, GlobCover 2009 uses inputs from a time series of MERIS FR (fine resolution) from the 300m sensor on board the ENVISAT satellite mission[8]. The MERIS instrument is a wide field-of-view "pushbroom" imaging spectrometer measuring the solar radiation reflected by the Earth in 15 spectral bands from about 412.5 nm to 900nm (Rast et al., 1999). MERIS is designed to acquire data over the Earth whenever illumination conditions are suitable (GlobCover, 12). The instrument's 68.5 field of view around nadir covers a swath width of 1150 km at a nominal altitude of 800 km enabling a global coverage of the Earth in three days. Five identical optical modules arranged in a fan shape configuration share this field of view.

[1] Joint Research Centre
[2] European Environment Agency
[3] Food and Agriculture Organization of the United Nations
[4] United Nations Environment Programme
[5] Global Observations of forest and Land Cover Dynamics
[6] International Geosphere-Biosphere Program
[7] European Space Agency
[8] Envisat was launched by ESA in March, 2002. After ten years of service, the Envisat mission ended on April 8, 2012 after unexpected loss of contact to the satellite

Spatial sampling by the Linear Charge Couple Device (LCCD) allows tracking in the across-track direction while the satellites motion provides scanning in the along-track direction (GlobCover 12). The spatial bi-dimensional image is created from the gathering and processing of subsequent images as ENVISAT is in motion. This greatly aids in the production of the GlobCover products. The GlobCover processing chain is developed with two modules: [1]pre-processing- which produces the MERIS FR mosaics that blanket the Earth with 2592 tiles (72 horizontal x 36 vertical), and [2]classification- which produces the final land cover map.

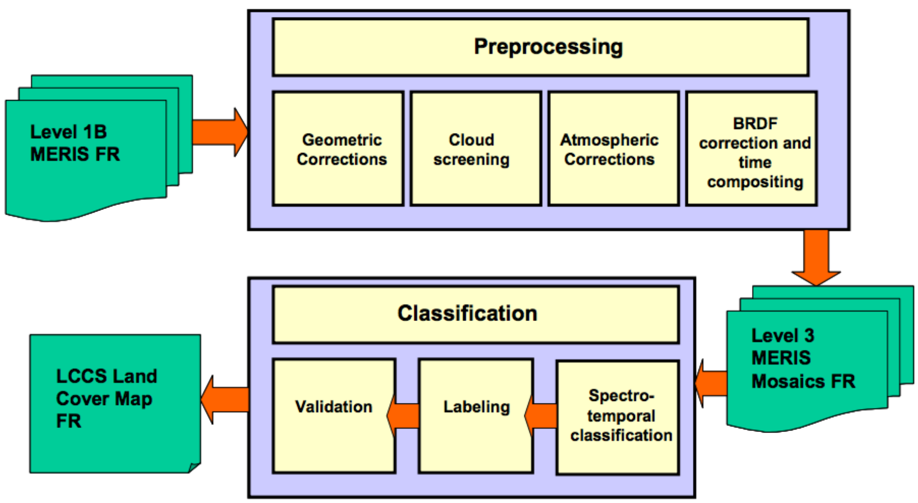


Figure 1. Algorithmic principles of the GlobCover chain

Figure 15: Algorithmic principles of the GlobCover chain

The land cover classification process described below:

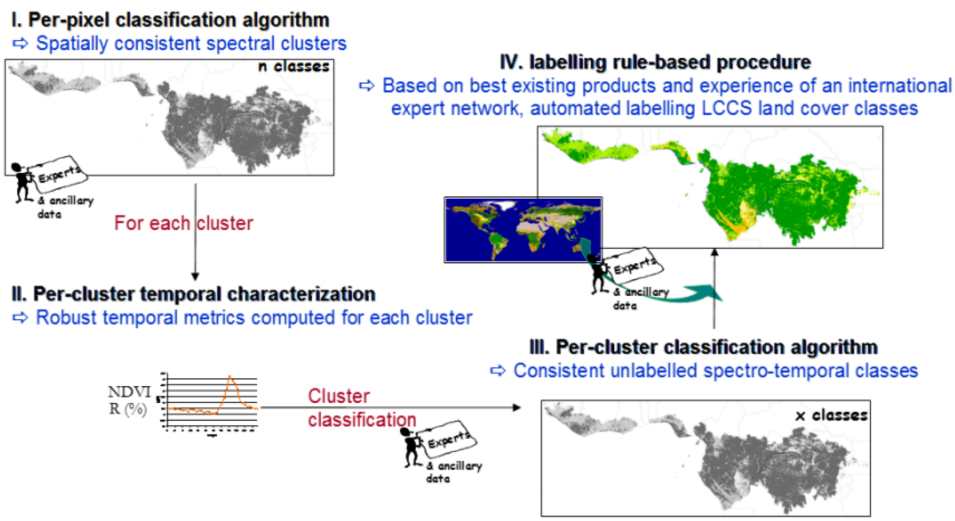


Figure 3. Scheme showing the principle of the classification algorithm starting with biweekly mosaics

Figure 16: Schematic showing biweekly mosaics

The classification process is what converts the MERIS FR mosaics into the global land cover map that is associated with the UN LCCS (Land Cover Classification System) legend. This hierarchical classification system allows for adjustments in thematic details depending on the amount of information available to describe a certain land cover class. Using this legend (containing 22 classes) allows GlobCover2009 to be compatible with GLC2000's land cover classification.

4.2.2: Common issues of uncertainty facing global land cover datasets
4.2.3: Semantic

One of the most powerful applications of land cover data sets is the potential to systematically track land use change across various scales. Part of the design in products such as GlobCover is to integrate global data sets of different temporal settings (e.g. 2005 vs. 2009) to better facilitate research within land change science. However, as technology and methodologies have advanced over the past decades, difficulties in sharing such datasets have presented challenges. One such problem facing the integration of data developed by different parties is *semantic interoperability* (Bishr, 1998; Sheth, 1999). Semantic interoperability attempts to account for a vast range of issues and approaches to resolve situations with complicated histories" (Harvey et al. 1999, 225). Semantic interoperability often fails in the context of LULC because "any classification system used for LULC data is to some extent subjective" (i.e. dependent on the original purpose of the study) (Feng et al. 2004, 230.)

A second problem concerns category names. For example, GlobCover2009 uses the Land Cover Classification System (LCCS) which was developed by the Food and Agriculture Organization (FAO) and the United Nations Environment Programme (UNEP/IUCN). The system was developed with the following characteristics in mind: *flexibility, consistency, comprehensiveness, comprehensibility, and applicability.* LCCS allows the definition of mixed classes, and for each defined class LCCS creates a Boolean formula (comprising the classifiers used), for a unique numerical code and a standard name (Herold et al., 2008, 4).

MODIS utilizes two vegetation index algorithms to enhance vegetation signal from measured spectral responses. The standard normalized difference vegetation index (NDVI) is referred to as the "continuity index" (Huete et al., 1999). The second is the enhanced vegetation index (EVI) that improves sensitivity to high biomass and vegetation monitoring through a de-coupling of the canopy background signal and a reduction in atmosphere influences (Huete et al., 1999). The primary land cover scheme is provided by an IGBP land cover classification. Noted by Feng, "theoretically, an expert with sufficient domain knowledge would be able to tell how similar two vegetation categories are and thus immediately determine the reusability of a particular LULC dataset" (Feng et al., 2004, 230). The issue of course, is that an expert with proper knowledge may not be present.

4.2.3: Decreases in Thematic accuracy

The past decade has seen a number of global datasets containing higher resolution and more sophisticated algorithms for classifying land cover. Following these products has been a handful of studies examining the spatial and thematic disagreements between these datasets. An example of an application used to measure disagreement in land cover between a pair of land cover maps is the Minimum Measurable Disagreement (MMD). For instance, each (aggregated) grid cell of each land cover dataset contains a minimum and maximum cropland or forest cover. In order to calculate the disagreement at each pixel one compares the range of cropland/forest cover by examining the amount of definitional overlap (Fritz et al., 2011, 3). Where there is overlap in definitions (think semantic interoperability) the MMD is 0, and where there is no overlap, MMD is calculated. For example, if an aggregated pixel of cropland for GlobCover is 0-40% and for MODIS is 60-100%, the MMD is 20% which takes the most conservative assessment of disagreement. Results from (Fritz et at 2011) notes that "360 Mha are identified as cropland in GlobCover but as non-cropland in MODIS, which is a discrepancy that equates to approximately 20% of the global cropland area" (Fritz et al. 2011, 5). This degree of uncertainty can be very problematic as these datasets are downloaded by tens of thousands of people. For reference by May 2011, GlobCover2009 (released on December 21, 2010) had been downloaded over 50,000 times. Many point out "these maps cannot be used for land cover change detection since the error in the original map is higher than the change detected" (Fritz et al. 2011, 5)

4.2.4: A few tools in the toolbox

4.2.5: Fuzzy Logic

A noteworthy application that seeks to improve upon disagreements in land cover datasets is the creation of a hybrid land cover product using fuzzy logic. Fuzzy logic is used in many GIS applications to address the problem of uncertainty, and has recently been used to incorporate expert knowledge (See et al. 2006, 1740). This technique, if properly administered, can be used to compare land cover products that differ fundamentally in terms of production based on inputs from expert knowledge (See et al. 2006, 1745). In this particular study, a set of fuzzy membership matrices were created by capturing the perception of experts on how well land use classes at a given reference area described the given classification of the map. The perceptions of the experts were recorded on a linguistic scale of 1 (absolutely wrong) to 5 (absolutely right). When comparing GCG-2000 and MODIS land cover datasets on a pixel-by-pixel basis using a Boolean and two fuzzy operators (minimum and maximum) one can calculate the fuzzy agreement. The results show that the disagreement is more severe if in the pixel-by-pixel comparison shows a bare area class on one map and a forest class on the other (See et al. 2006, 1741).

4.4.: Anthro Layer

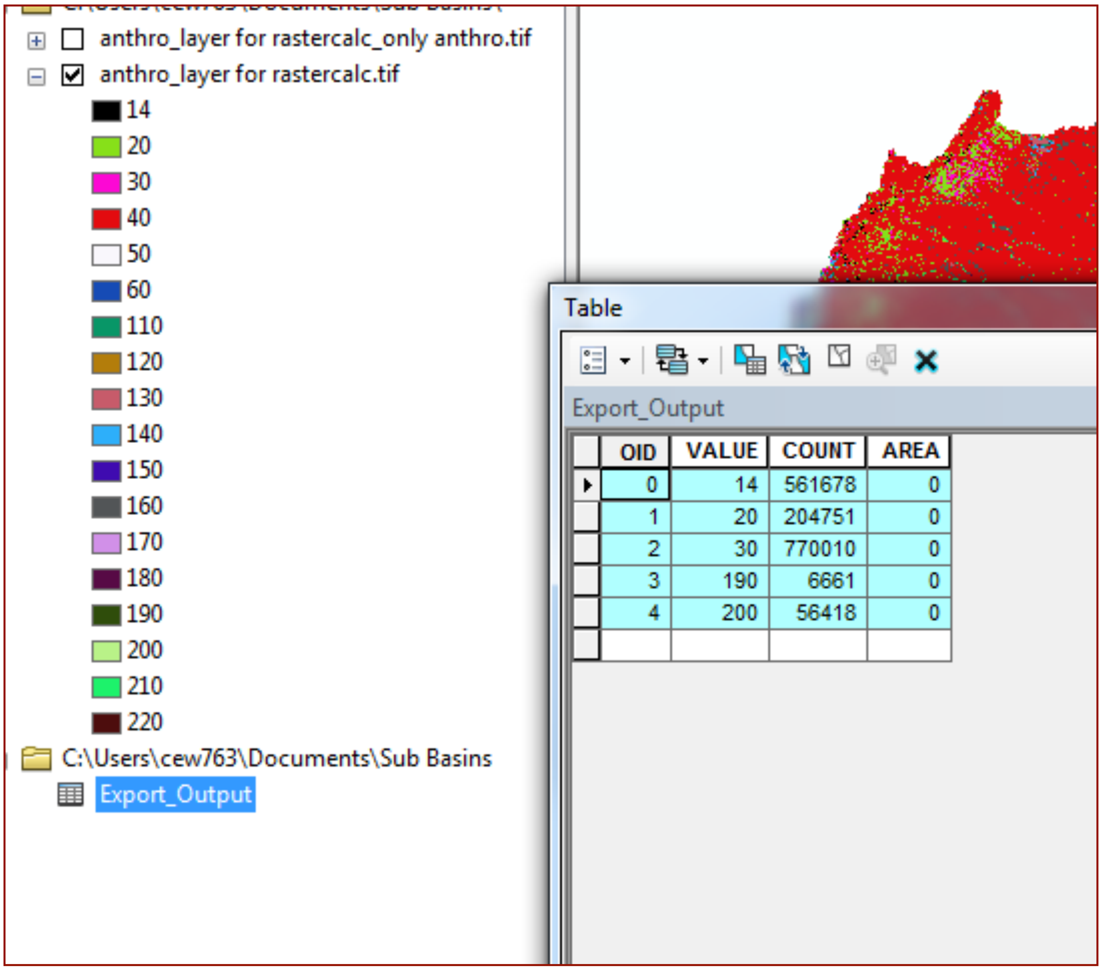


Figure 17: Creating the Anthro Layer

Using the Globocover2009 dataset I created a layer called anthro layer which comprised of the Mosaic croplands/Vegetation, Mosaic vegetation/Croplands, artificial areas, and bare areas (numbers 14, 20, 30, 190, and 200). Once created and exported that layer had to be reclassified in ArcGIS using raster reclassification to make them 1 value Next downloading UMD global deforest (2000-2013) which was published by Hansen et al. 2013 *High-Resolution Global Maps of 21st Century Forest Cover Change* using a combination of raster calculator and then mosaicked the sets. Next Zonal statistics as Table was used to calculate area per basin paying careful attention to meter to kilometer conversions and also pixel size was 500. Results yielded number of pixels per sub-basin that were "anthrolayer" then divide this number by total pixels per sub-basin – result is based on a 500 meter squared pixel. Once these pixels were then calculated as kilometers squared, the area was then divided by the area of the basin and multiplied by one hundred which represented the percent deforested. Note: This initial number is only counting the number of pixels that were not previously classified as the anthro layer. Therefore this method does not account for issues associated with defragmentation of forests which will be addressed later with the expanded cells method. Expanding cells was intended to simulate a more realistic area of deforested and fragmented systems.

4.5: Protected Areas

In order to obtain information on protected areas, this study used the World Database on Protected Areas (WDPA). The WDPA is compiled by the United Nations Environment Programme and the IUCN, utilizing member organizations in 140 countries and has been doing so since 1981 (UNEP/IUCN 2009).

Similar to issues of accuracy facing any project at global scale, the WDPA's accuracy depends on the reporting process (Gaston et al. 2008). Notwithstanding, it is recognized "as the most comprehensive and authoritative database available on protected areas and is commonly used in global studies of conservation" (Nelson, Chomitz 2011)(Joppa et al. 2010)(Tang el al. 2011). This database applies a rigorous, consistent and detailed set of criteria to the identification and classification of protected areas (Dudley 2008). Protected areas are defined as: "a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values" (Dudley 2008). Protected areas in this study include all nationally (IUCN protected area management classes I through IV as well as unknown) and internationally (UNESCO MAB reserves).

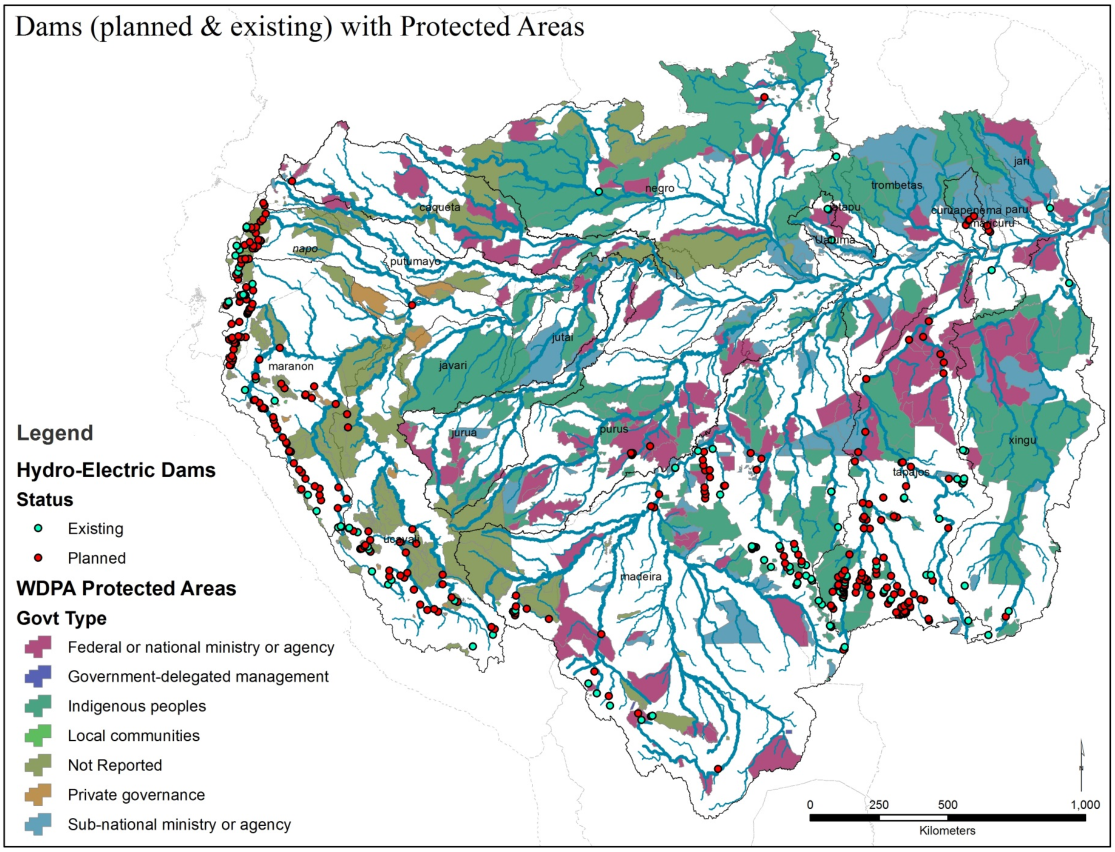


Figure 18: WDPA Protected Areas

4.6: Biomes

In order to collect data on different biomes within the study region, I chose to use the *Terrestrial Ecoregions of the World* which was created by the Conservation Biology Institute and uploaded to databasin.org in October 2010 and last updated (upon writing) on May 13, 2011. This dataset represents 825 terrestrial ecoregions of the world. The ecoregions (as defined by this dataset) are “relatively large units of land containing distinct assemblages of natural communities and species, with boundaries that approximate the original extent of natural communities prior to major land-use change” (Olsen et al. 2001). This dataset was constructed based on hundreds of previously delineated biogeographical studies which were then refined and synthesized in workshops over a 10 year period. Ecoregions are nested within two –higher order classifications; 14 biomes and 8 bio-geographical realms.

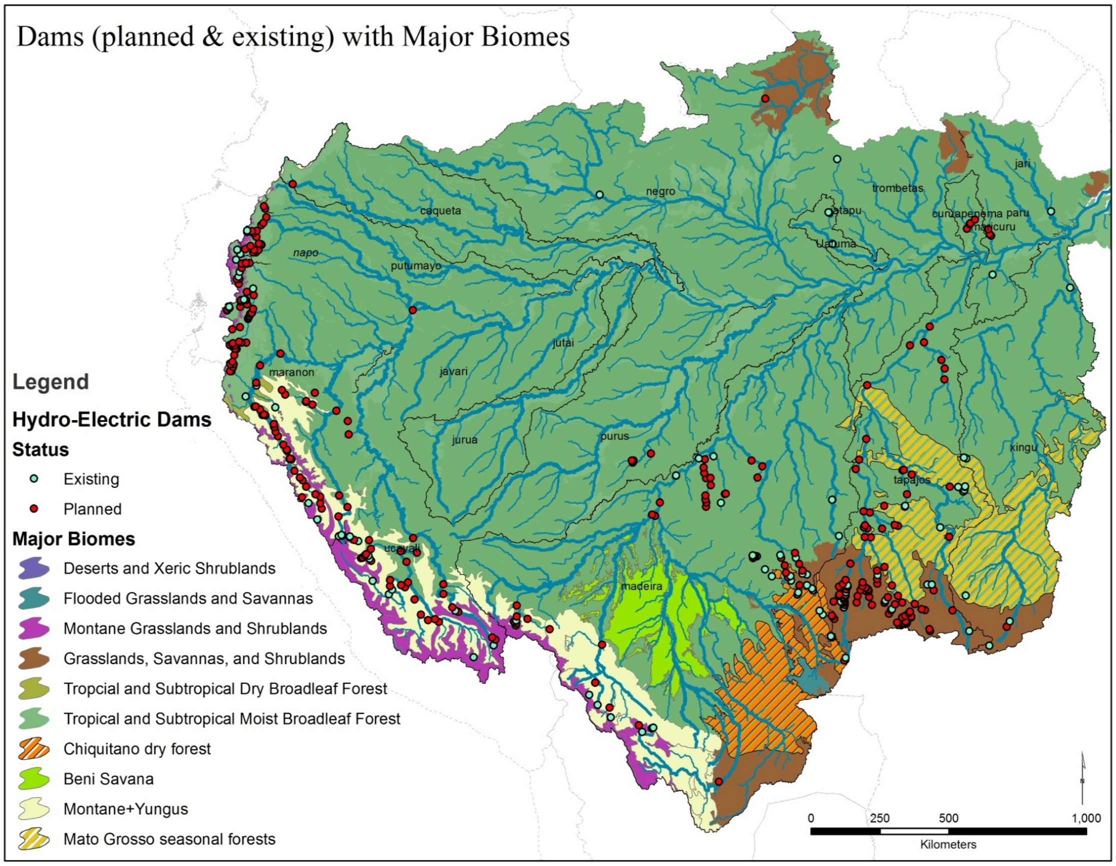


Figure 19: Biomes of the Amazon Basin

4.7: Deforestation within Sub Basins

Deforestation within each sub-basin was calculated by using the previously mentioned technique of combining Anthro layer in conjunction with the UMD global deforest (2000-2013) which was published by Hansen et al. 2013 High-Resolution Global Maps of 21st Century Forest Cover Change. These datasets were combined using raster calculator then mosaicked. Results yielded number of pixels per sub-basin that were “anthrolayer” then divide this number by total pixels per sub-basin – result is based on a 500 meter squared pixel. Once these pixels were then calculated as kilometers squared, the area was then divided by the area of the basin and multiplied by one hundred which represented the percent deforested.

Result shown below:

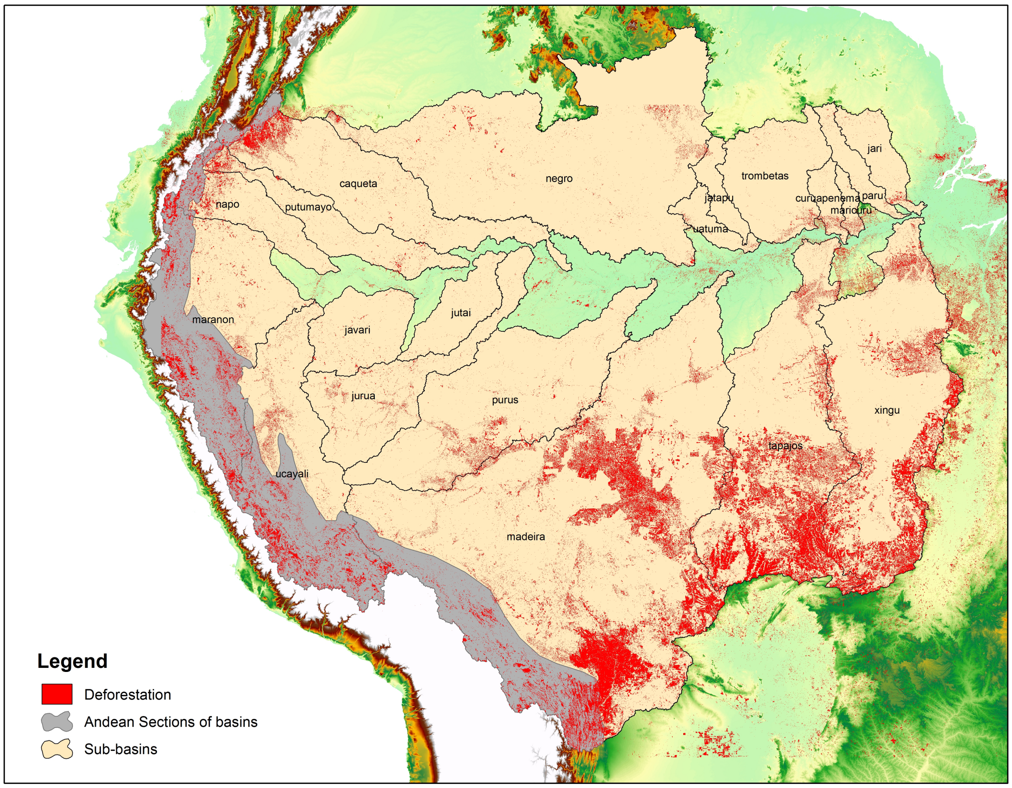


Figure 20: Deforestation with the Andean Zone denoted

As an experimental process to try to gain a more "realistic" spatial extent of fragmentation associated with deforestation we chose to use the expand cell function within ArcGIS at various levels. The idea is that although the above "anthro layer" is picking up cells which are not virgin forest, it does not account for small areas in between these cells.

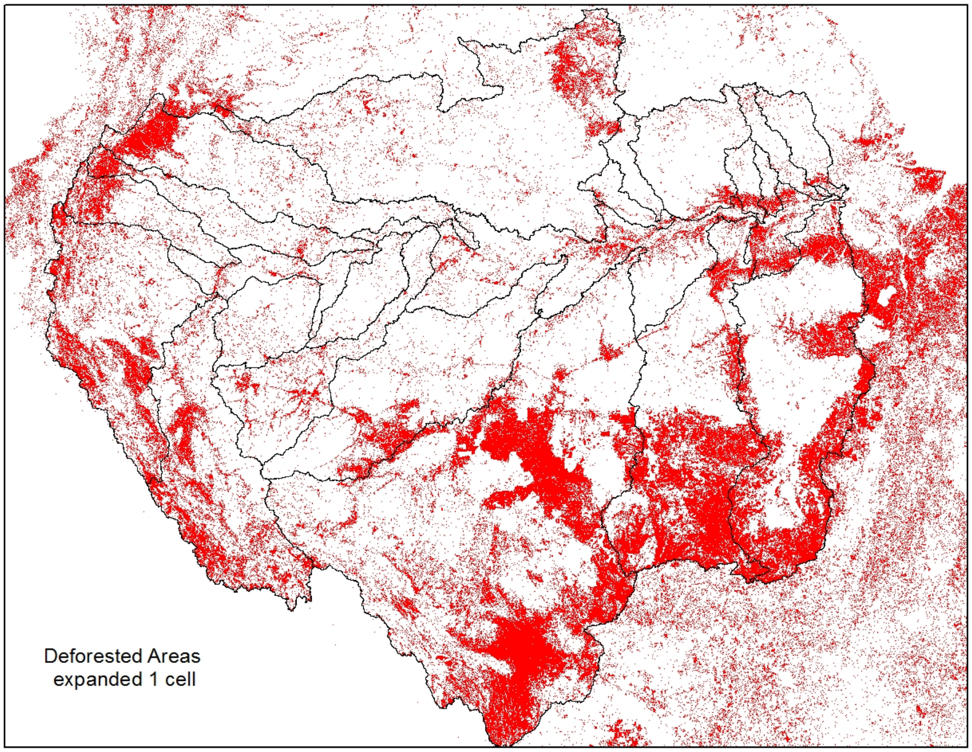


Figure 21: An example of expanding anthro layer by 1 cell

Worth noting is that at this scale one cannot differentiate the different pixels as they bleed together when zoomed out, however, up closer inspection, the fishbone patterns we are used to seeing appear:

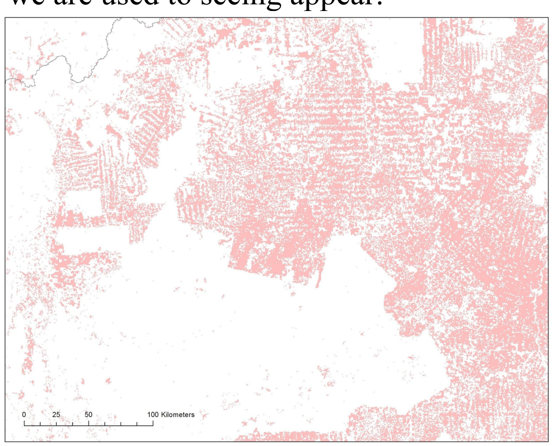


Figure 22: Zoomed in version of Anthro layer

For example, expanding by 5 cells, or 2.5km we saw results below:

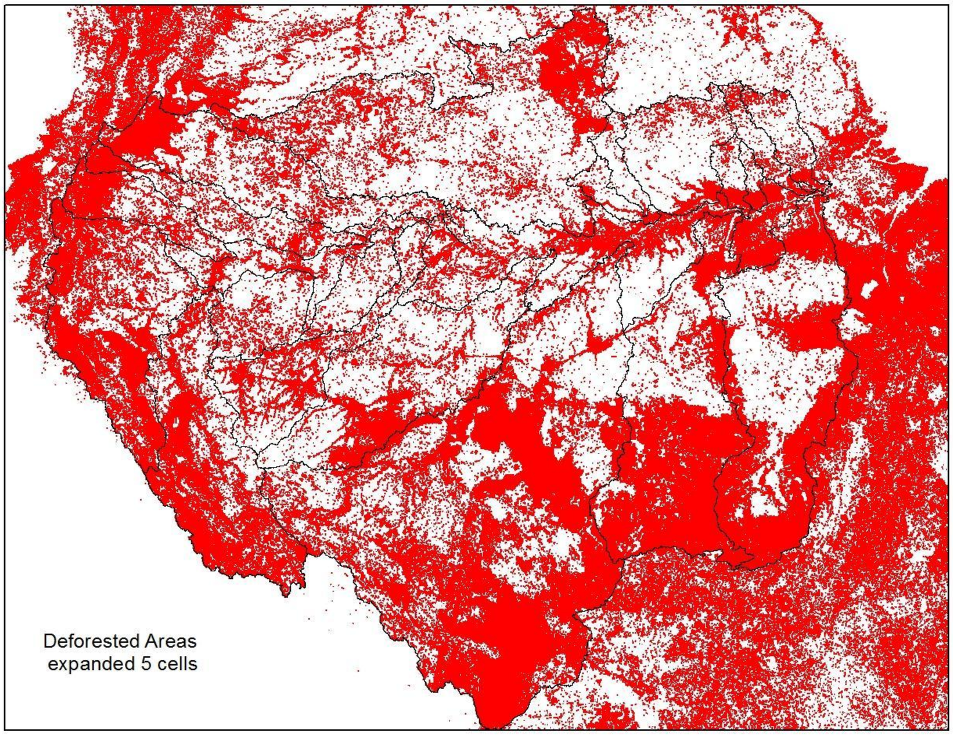


Figure 23: An example of expanding anthro layer by 5 cells

The above figure demonstrates the pervasive nature of Deforestation and fragmentation within (in the case of Figure 23) the central part of South America.

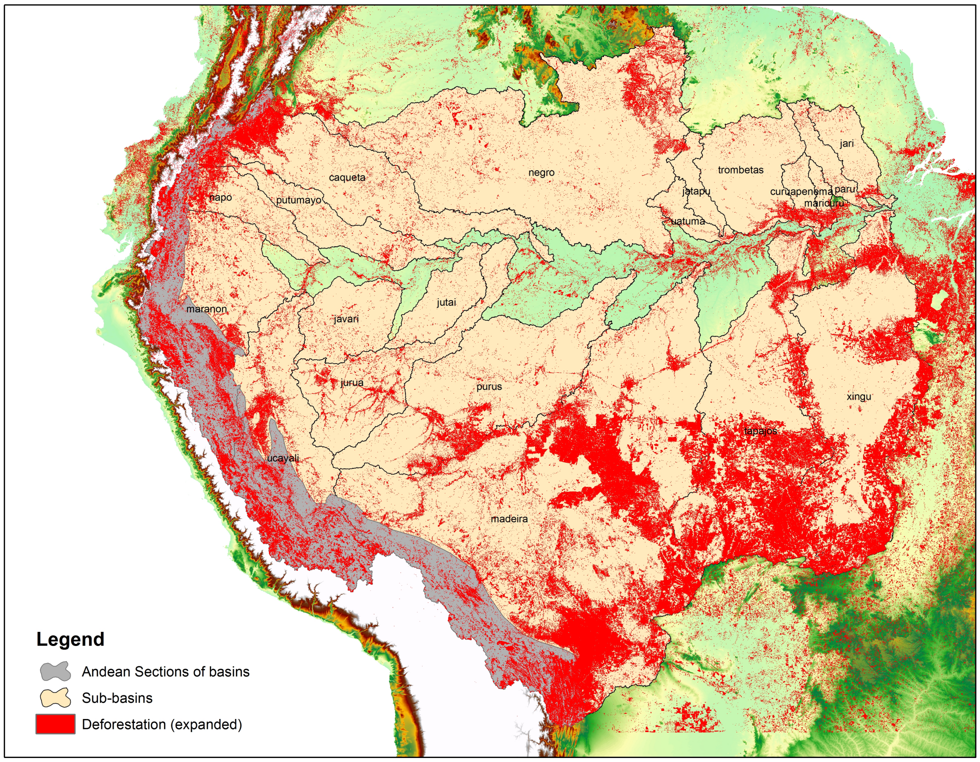


Figure 24: Deforestation map showing anthro pixels expanded by 1 cell

For the rest of the study, 1 cell expand was used on the Andean section of the basin, while 5 cell was used for the rest of the basin. All subsequent calculations will be a reflection of that methodology. Colored below are the areas within each individual sub-basin which are upstream of the upstream most dam. In the figure below (Figure 25) one can see the upstream and downstream areas of each basin. Indicated by Orange is the deforestation below the dam, and Red indicates deforestation upstream of that dam. Note the deforestation layer is the original deforest layer pre expand cell technique to give a better idea of spatial extent of upstream vs. downstream sections without the cartographic cluttering of expanded cell deforestation – which has very depressing realistic implications and demonstrates the pervasive spatial nature of deforestation in the Amazon.

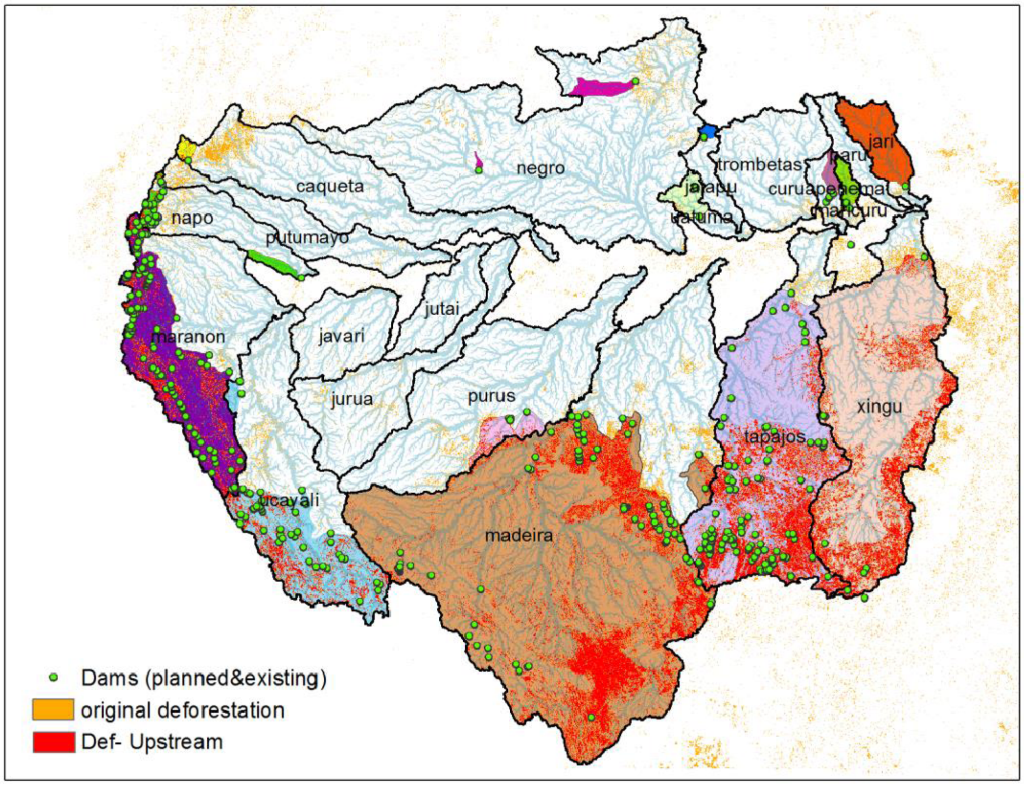


Figure 25: Deforestation (standard) upstream vs. downstream

The figure below (Figure 26) demonstrates the cartographic issues associated with pervasive deforestation issues once expanded deforestation technique was applied. To aid in the cartographic representation, orange represents (expanded) anthro layer downstream of the downstream-most dam each basin, and red represents all anthro layers upstream of the downstream most dam in each basin.

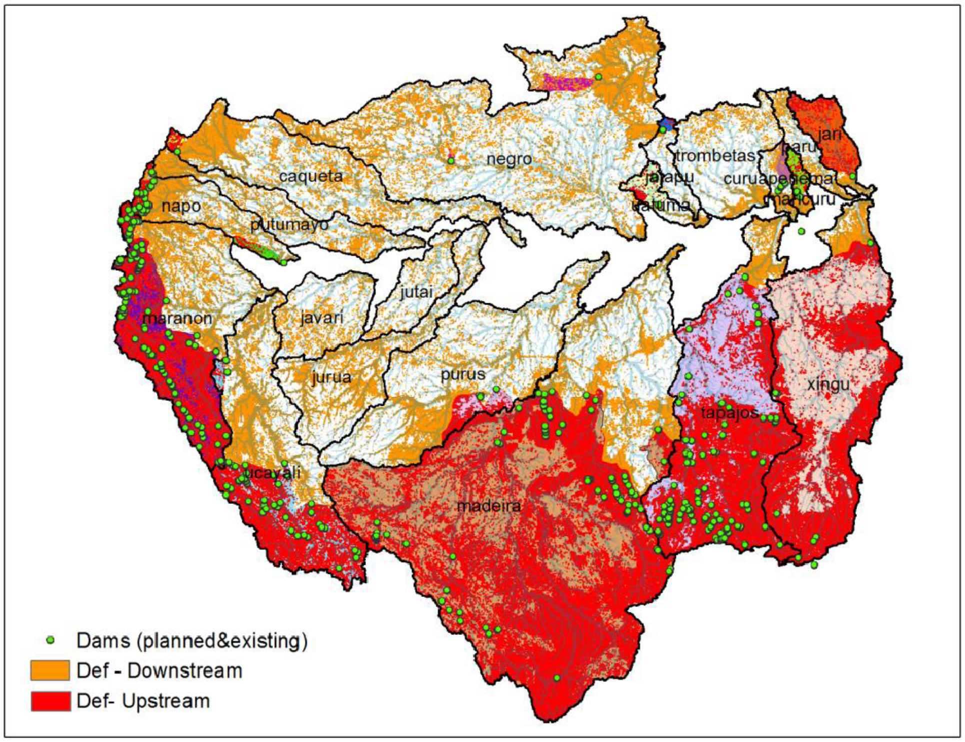


Figure 26: Deforestation using up-cell tool upstream and downstream

A Summary of Statistics produced from the aforementioned maps:

	Entire Basin					Upstream of lowermost dam				
	original			5 cells (2.5km)		original			5 cells (2.5km)	
Basins	area of basin (km2)	Deforested area (km2)	Percent deforested	Deforested area (in km2)	Percent deforested	area of basin (km2)	Deforested area (km2)	Percent deforested	area deforested	Percent deforested
caqueta	268,951	16,079	5.98	120,301	15.86	5,073	471	9.27	3,894	76.75
curuapenema	28,277	1,149	4.06	11,931	15.24	8,124	22	0.27	1,537	18.92
jari	59,206	1,064	1.80	21,771	7.48	51,982	389	0.75	16,366	31.48
jatapu	34,494	232	0.67	5,725	3.12	3,055	20	0.65	970	31.75
javari	109,204	1,356	1.24	36,334	5.63	109,204	0	0.00	36,329	33.27
jurua	188,917	4,587	2.43	82,414	11.16	188,917	0	0.00	82,402	43.62
jutai	78,109	359	0.46	19,102	3.07	78,109	0	0.00	19,105	24.46
madeira	1,370,045	208,294	15.20	921,689	33.62	1,078,878	203,883	18.90	805,905	74.70
maranon	363,287	33,401	9.19	246,970	26.42	193,882	28,487	14.69	160,879	82.98
maricuru	16,133	1,002	6.21	7,843	23.67	10,883	83	0.76	2,876	26.43
napo	102,190	7,586	7.42	61,819	22.48	16,329	1,756	10.75	11,335	69.42
negro	712,612	15,580	2.19	265,921	9.30	13,218	171	1.29	5,832	44.12
paru	39,645	493	1.24	16,634	7.34	39,645	0	0.00	16,639	41.97
purus	377,154	11,550	3.06	135,636	11.28	23,487	2,804	11.94	14,457	61.55
putumayo	120,579	5,715	4.74	56,366	14.51	120,579	0	0.00	56,365	46.75
tapajos	492,527	112,472	22.84	348,098	43.94	452,059	113,414	25.09	319,196	70.61
trombetas	156,259	1,924	1.23	39,194	5.57	156,259	0	0.00	39,215	25.10
uatuma	33,424	446	1.33	9,786	6.89	18,753	209	1.11	4,725	25.19
ucayali	352,301	33,764	9.58	246,539	28.20	165,694	27,238	16.44	144,083	86.96
xingu	511,165	83,897	16.41	290,551	33.30	482,348	82,780	17.16	269,018	55.77

Table 2: Comparative % Deforestation: Original vs. 5 cell expanded

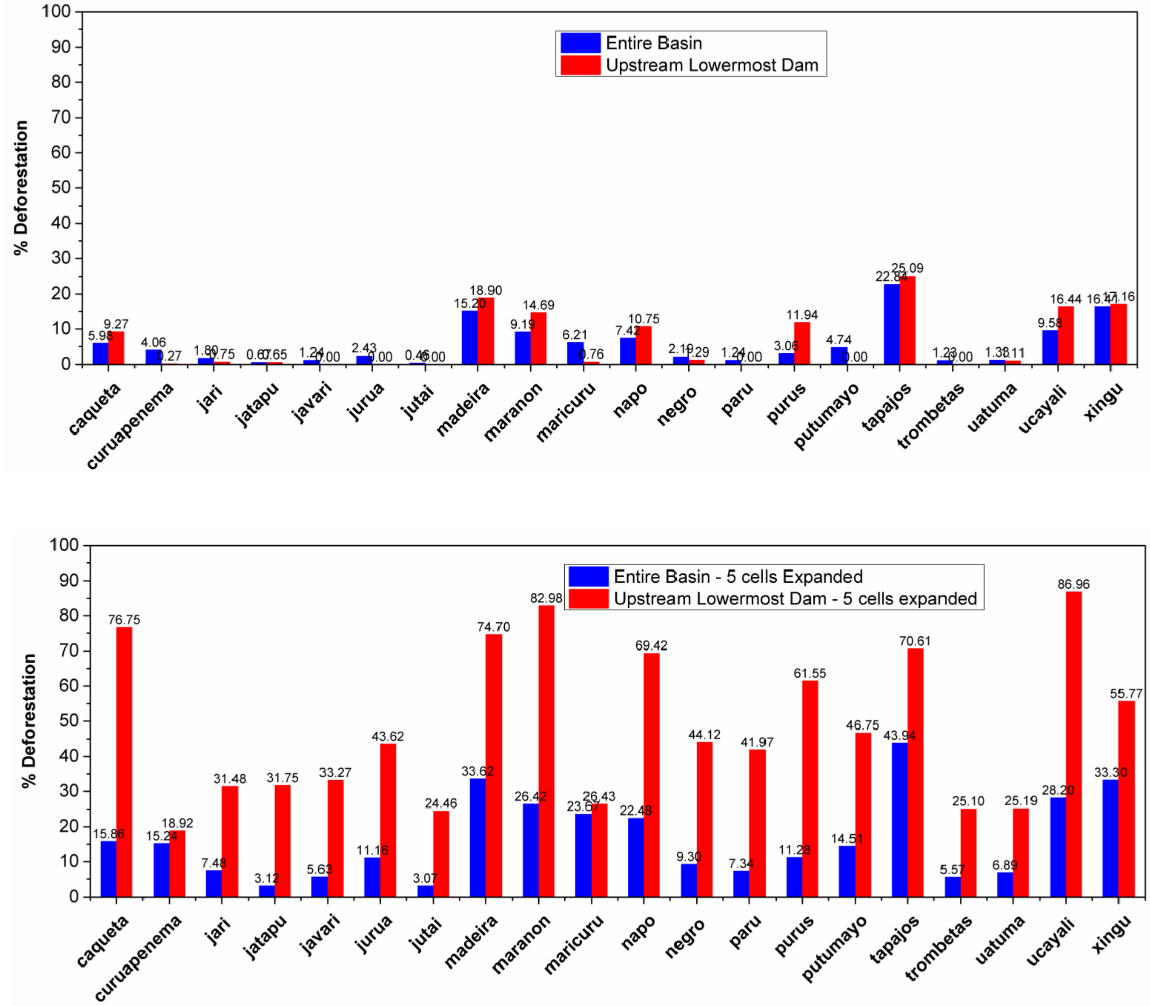


Figure 27: Comparing upstream vs downstream on standard and up-cell deforestation

Figure 27 is meant to provide an additional graphical representation of disparity of deforestation between the upstream (of dams) section and the entire basin of every sub-basin. Worth mentioning is the increased disparity once the expanded cell technique is implemented. For example, original deforestation calculations of the Xingu and Tapajós are similar in their respective upstream and total basin % deforested at ~16% and 23% respectively. However, the difference in percent deforested upstream vs. entire basin changes significantly when the expanded cell techniques is employed. For instance once expanded, the upstream section of the Xingu percent deforested is ~56% whereas the basin as a whole is near 33%. In the case of the Tapajós we find ~70% of the basin upstream of the downstream most dam deforested as opposed to ~43% for the basin as a whole.

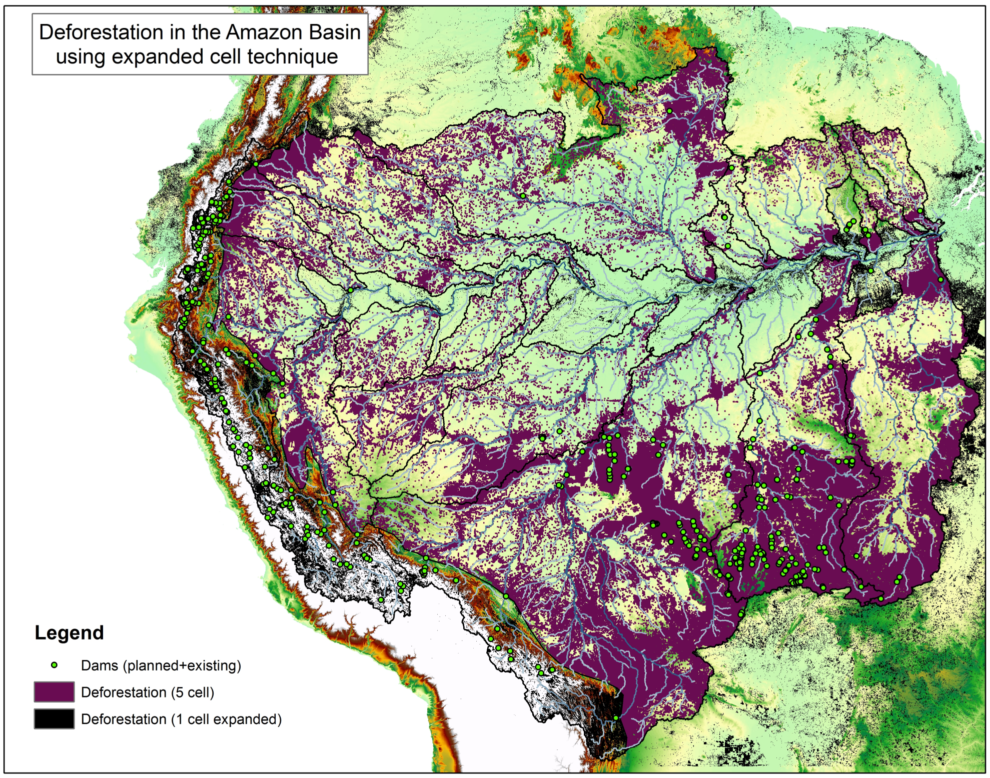
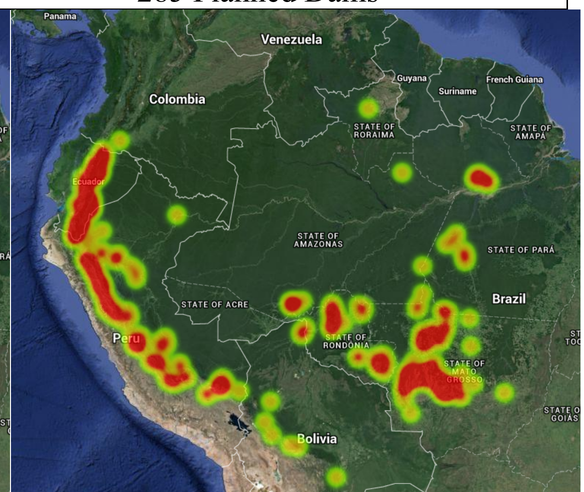


Figure 28: Deforestation base layer used in vulnerability studies

The above figure (Figure 28) provides a cartographic representation of the final product used in the vulnerability indexes in the proceeding sections of the thesis. This map graphically represents the merging of the 5 cell expanded cell technique (previously described) performed on the anthro layer in the lowlands of the Amazon basin (in purple) combined with the 1 cell expanded cell technique applied to the Andean zone of the Amazon (in black).

Chapter 5 Results – A potential future of the Amazon

Below are heat maps linked to the Dams Database showing current and future conditions. Heat maps like these provide an added visual advantage to recognizing that dam impacts are spatially pervasive and affect more than just the 'dam site'. These particular heat maps help illustrate the grim fate of the Amazon if dam construction continues unimpeded.

121 Existing Dams	285 Planned Dams
	

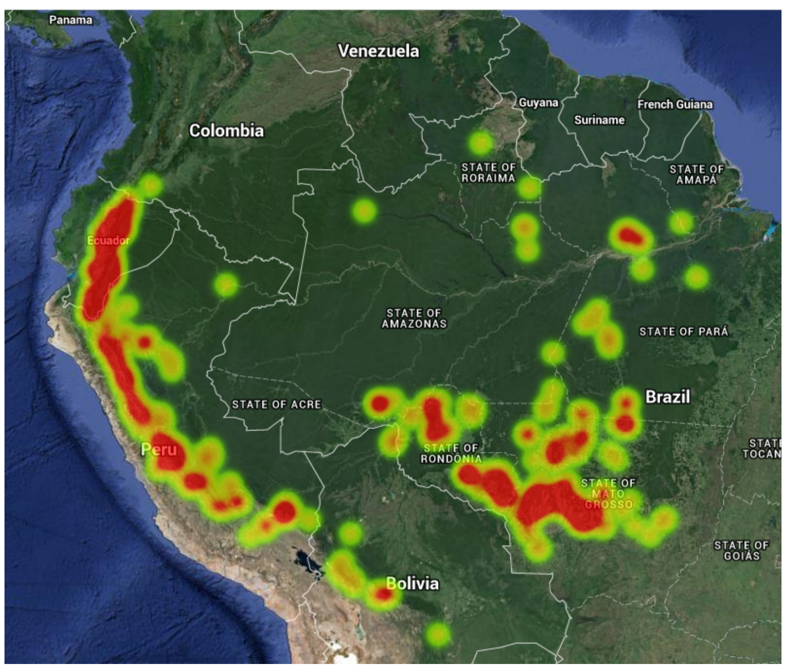


Figure 29: Heat Maps from the Database showing Dams (present and future)

Dams Present and Future Perspectives

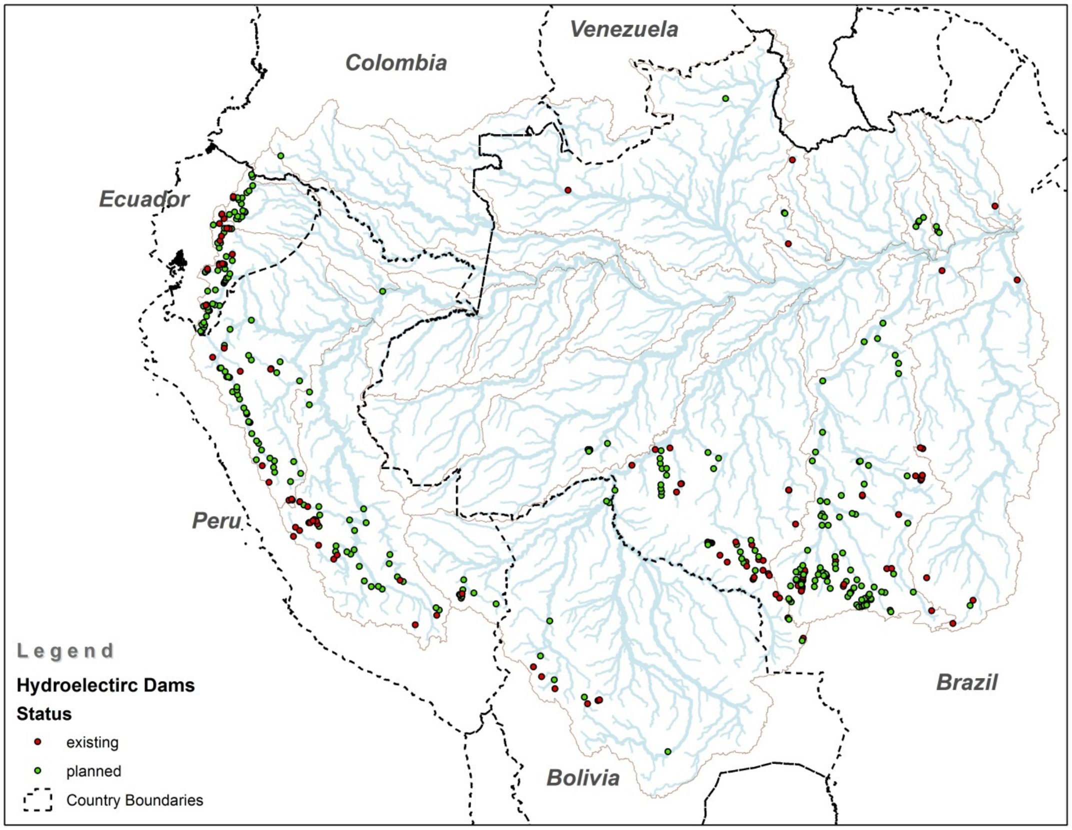


Figure 30: Dams: Planned vs. Existing

5.1 Dams in Protected Areas by country

On a dams-per-country basis, there are obvious inequalities between country size and number of dams. Take for example, Peru vs. Ecuador who have a combined (planned+existing) 106 and 76 dams respectively. Peru has some 79 planned dams and Ecuador 60, although in terms of total areas Peru is some 4.5 times larger. Brazil over twice as large as the Bolivia, Colombia, Ecuador and Peru combined has some 209 (planned and existing) dams in their Amazon Basin alone. Although Colombia relies on hydropower for national electricity, currently there is only one planned dam in the

Amazon basin. Bolivia concentrates the majority of their dams will be on the eastern edge of the Andes with plans for 9 adding their existing 6 in the Amazon Basin.

Below is a figure showing the both planned dams (in red) and existing dams (in blue) at a per country basis.

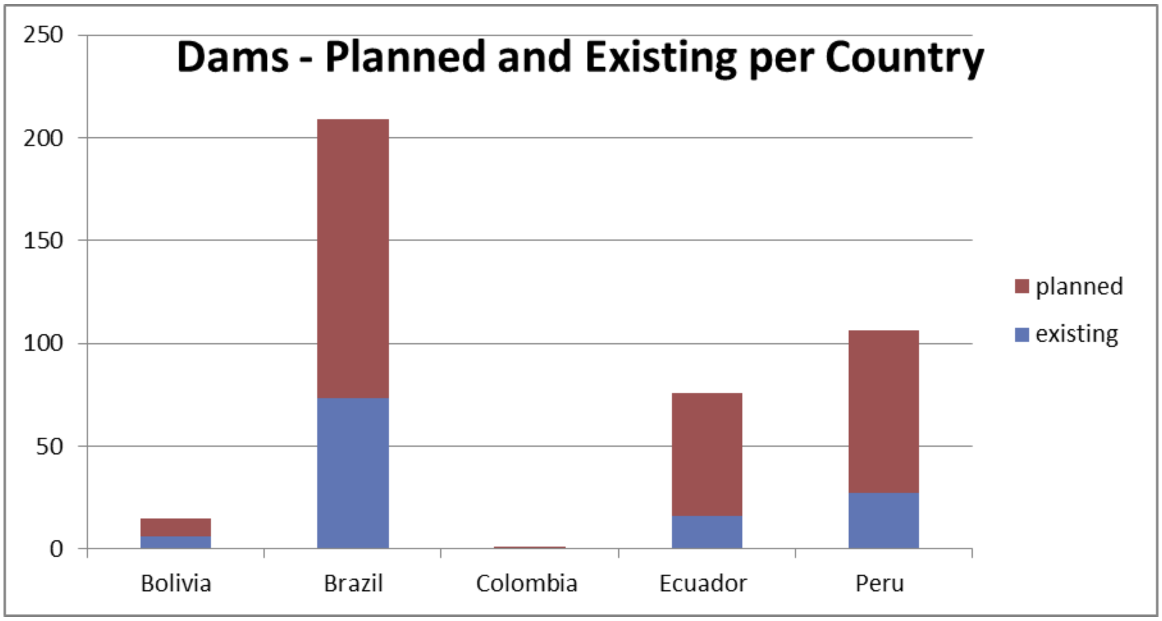
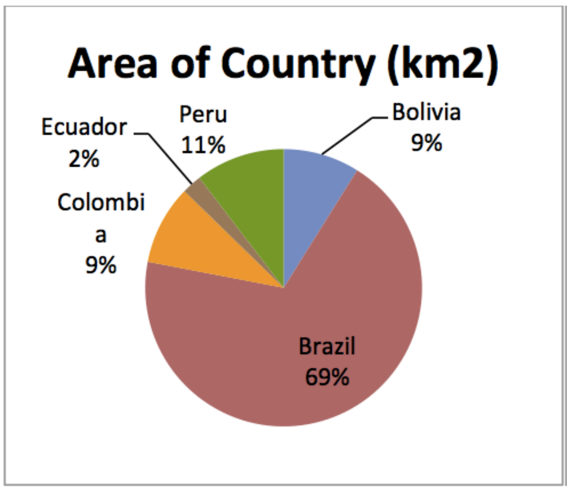


Figure 31: Distribution of Dams (planned vs. existing) per Country

Beneath this data are interesting nuances between countries that mix geo-physical restraints like rainfall, elevation and also social conditions like infrastructures, political power and historical tendencies. As mentioned, Ecuador and Peru show very similar numbers of planned dams in their futures (60 and 70 dams respectively) however in terms of area, Peru is some 4.5 times larger. One of the main drivers of Ecuadorian dams at present is the influence of Chinese construction companies who bring in their own workers to build hydro-electric dams on Ecuadorain rivers i.e. Coca-Coda Sinclair hydroelectric dam of 2010 was funded by a 1.7 billion USD load by Chima Exim Bank that went directly towards a Chinese Company (Hilton, Isabel. "China in Latin America: Hegemonic challenge?." Norwegian Peacebuilding Resource Center (2013). The multi-national nature of dam construction in South America is not unque to Ecuador however.



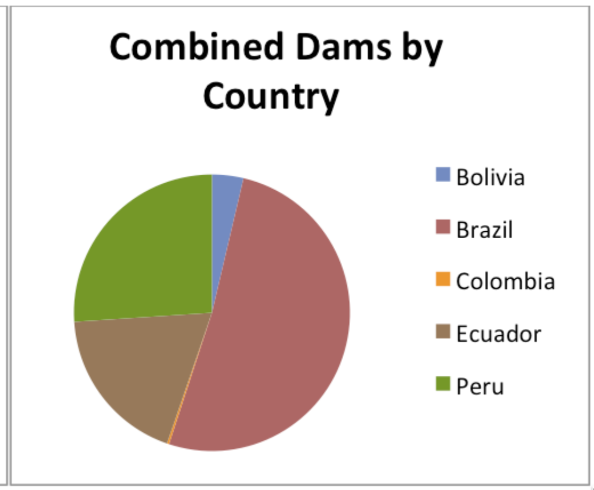


Figure 32: Areas of country and number of dams per country comparison

Data used in graphs below:

	Hydro-electric Dams			
Country	**DAMS**	**existing**	**planned**	**area of country (km2)**
Bolivia	15	6	9	1,098,580
Brazil	209	73	136	8,514,877
Colombia	1	0	1	1,141,748
Ecuador	76	16	60	283,560
Peru	106	27	79	1,285,000

Table 3: Hydroelectric Dams by Country

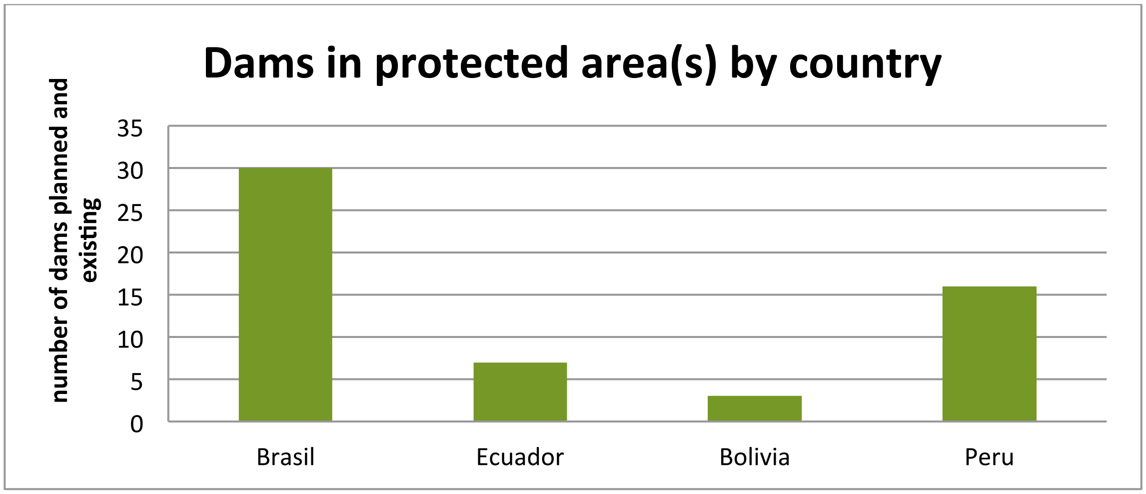


Figure 33: Dams in protected area(s) by Country

The above figure represents what one might expect in that due to Brazil's much greater area, they would have higher potential for Dam projects to overlap protected areas. However although Peru is slightly larger than Bolivia, Ecuador (at nearly a quarter of Bolivia's size) has over twice as many dams in protected areas as Bolivia. Drawing from this research as well as other other research and personal communication, Ecuador's race for extractive purposes in such a (relatively) small country with such high biodiversity is certainly disconcerting. Whats more, many of the basins in this study are actually international in that the basin actually spreads over multiple countries. It will be important in the future to recognize the upstream and downstream implications of these dams from not only a shared environmental sense but also politically.

5.2 Dams by Sub-Basin

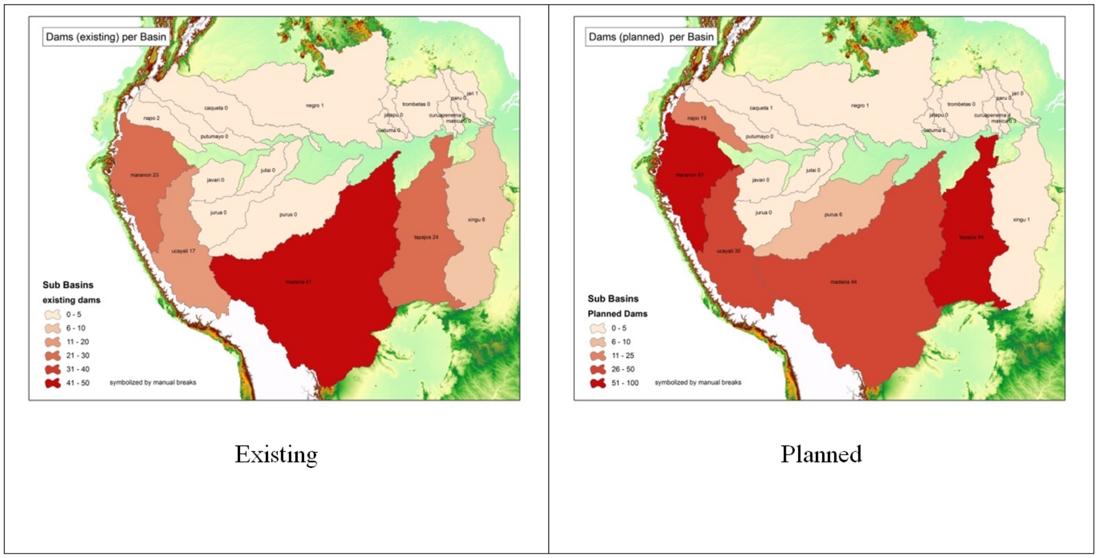


Figure 34: Choropleth map showing dams by sub-basin existing and planned

These choropleth maps provide accessibility to a large amount of data on a simple to follow interface. In the cases of Figures 34 and 35 the darker colors denote higher numbers of dams. One pattern one can deduce from these maps on dams varying by time (in this case present vs. future) is the spatial patterns shifting more towards the Andean Basins in the future while simultaneously lessening numbers of dams in the Xingu. In figure 35 one can see that a heavy concentration of dams will affect the Tapajós, Madeira and Ucayali more than other basins. Further in the study we will acknowledge issues related to sizes of basins.

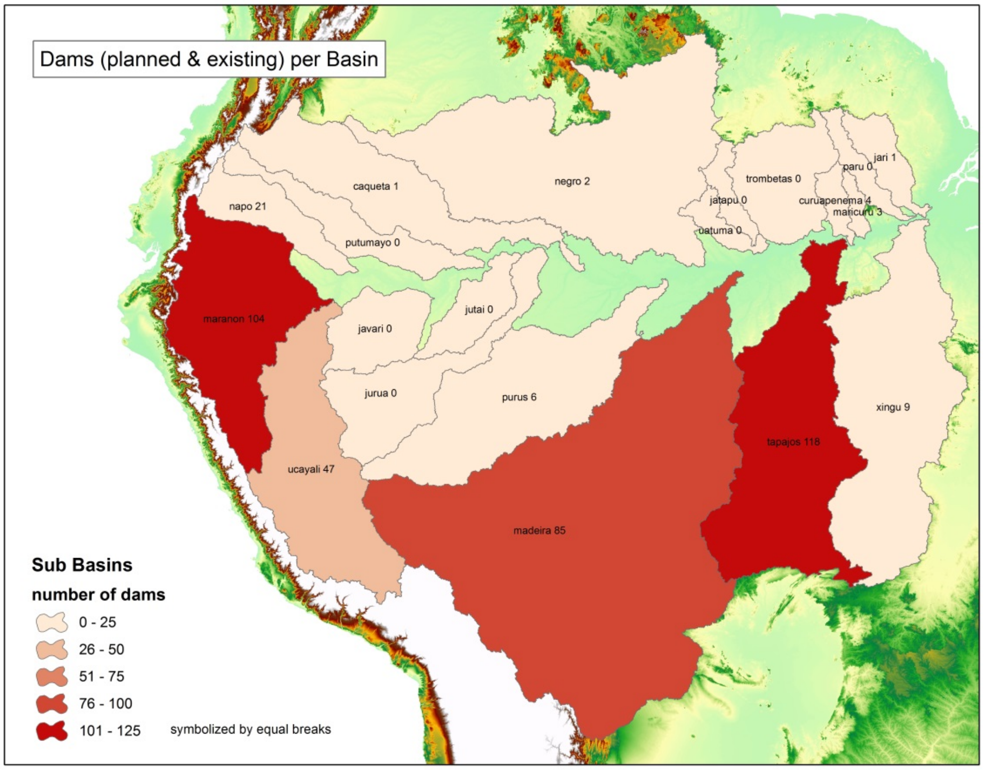


Figure 35: Choropleth map showing a potential future of dams by sub-basin

5.3 Dams in Protected Areas

Although the average amount of protected area per sub-basin is approximately 50%, we still find 41 planned and 8 existing dams are located within Protected Areas (WDPA Protected Areas Database). For this study we used data from The World Database on Protected Areas (WDPA), which is the only comprehensive global inventory of protected areas at global scale (Chape et al. 2005). There are acknowledged limitations within this dataset concerning both temporal (major updates to the database take place every 3-5 years) and spatial inaccuracies (where overlap between types of boundaries is possible). The chart on the below shows the geographic extent of the Protected Areas within the Amazon Fluvial Basin. The chart below shows the percentage of each Government Type of Protected Area.

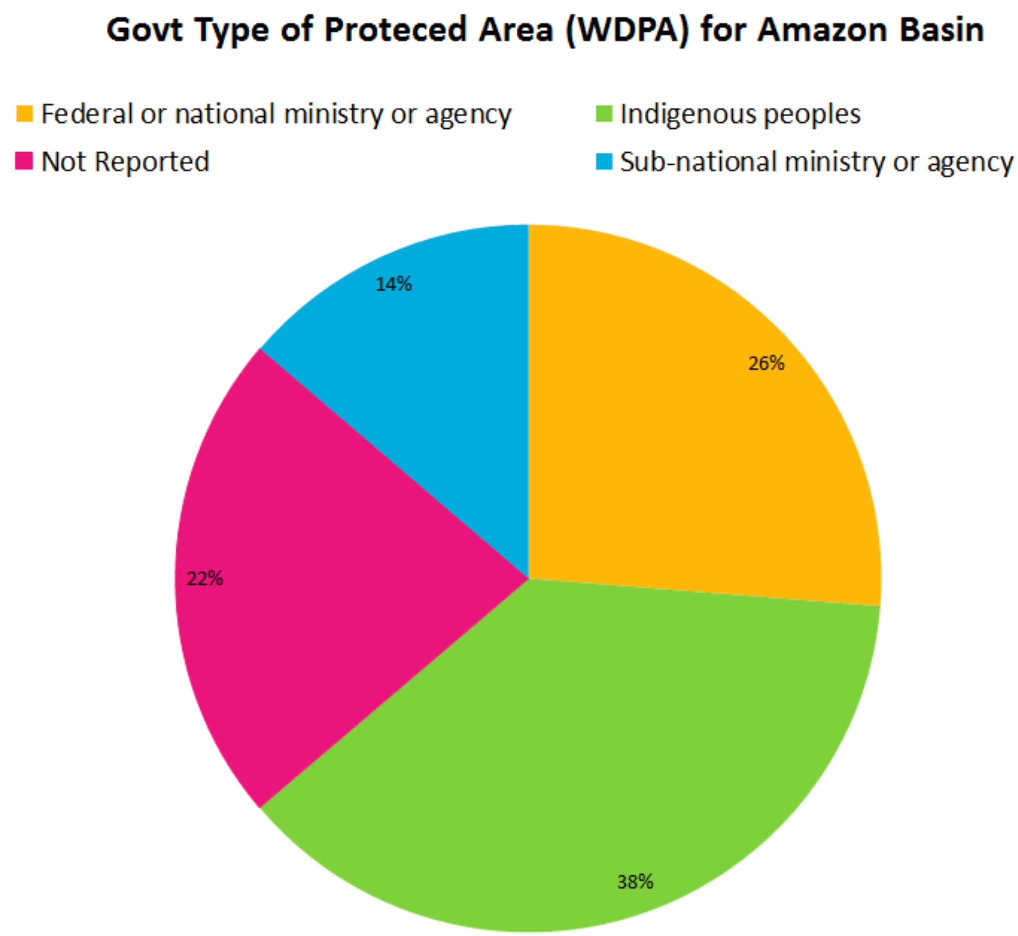


Figure 36: Government Types of PA for Amazon Basin

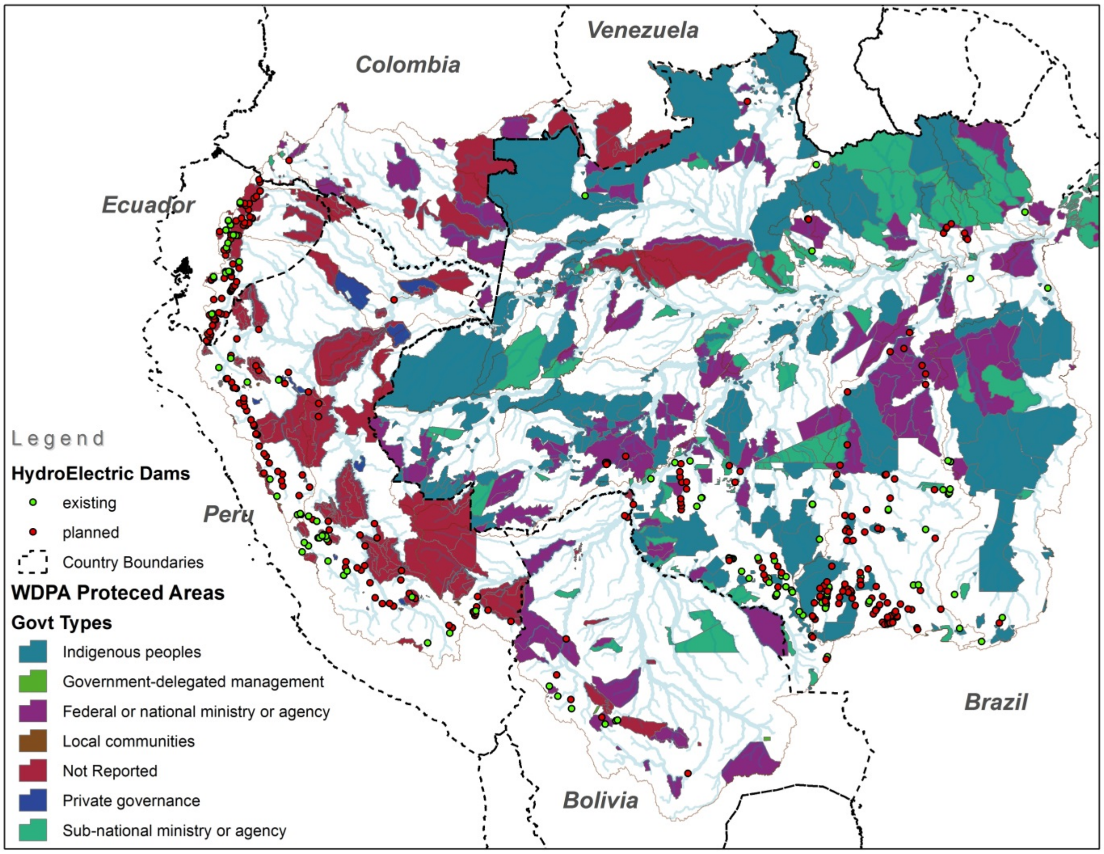


Figure 37: WDPA In the Amazon Basin

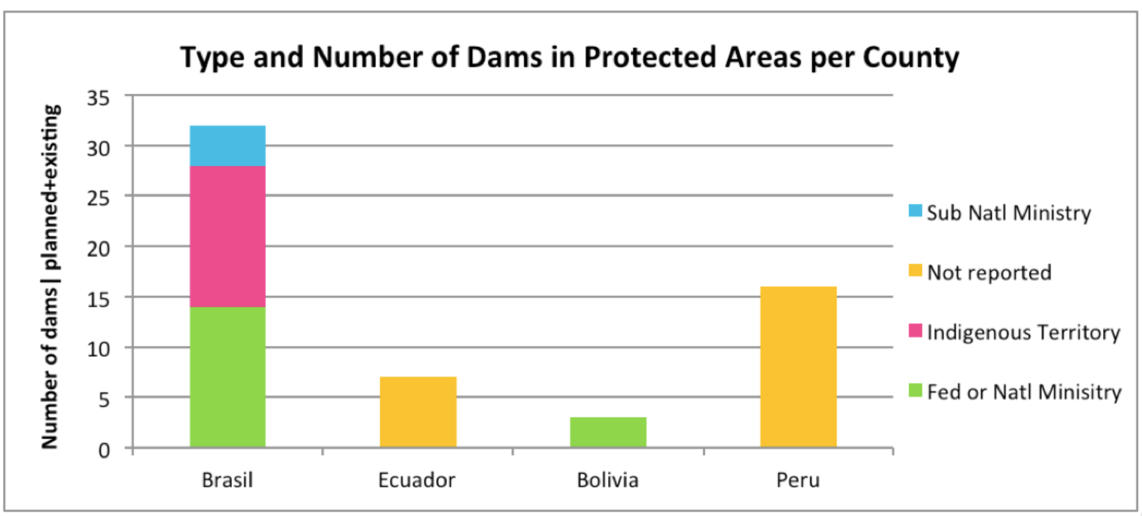


Figure 38: Type and Number of Dams in PAs

Of the 406 dam points (285 planned; 121 existing) in the Amazon basin, this study found only 41 planned dams and 8 existing dams within Protected Areas. Based on countries within the Amazon Basin, Brazil leads with 32 dams in Protected Areas, nearly half located in Indigenous Territory. Of Peru's 106 (79 planned and 27 existing) dams, there were 16 within the vaguely denoted "Not Reported" Protected Areas – as were Ecuador's seven.

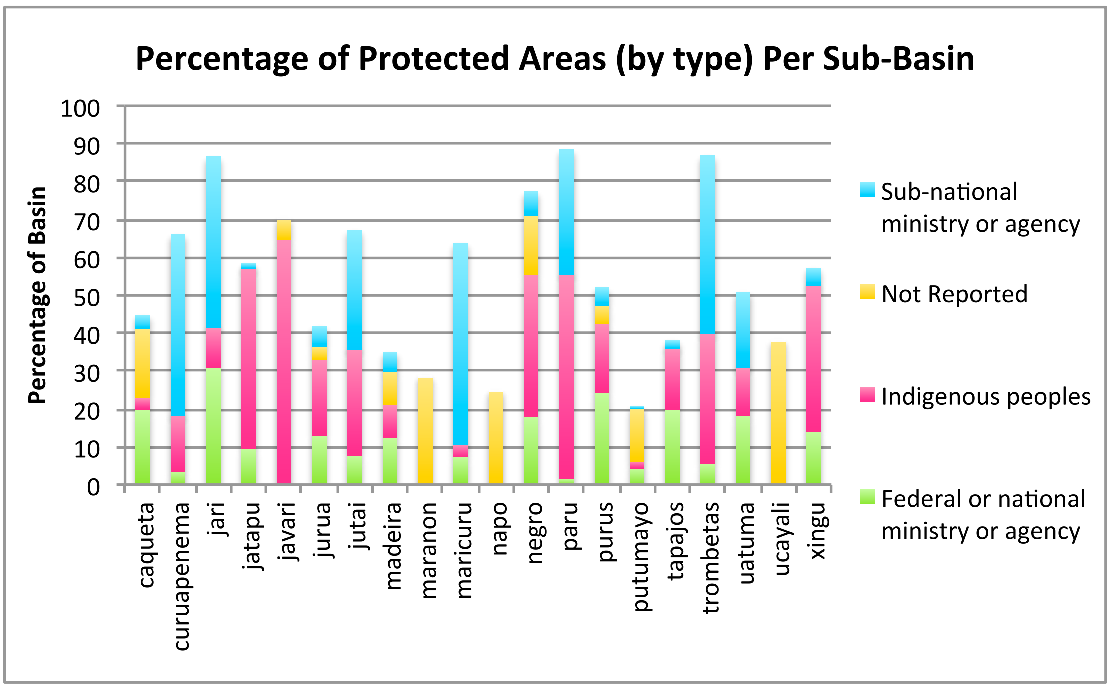


Figure 39: chart showing Percentage of Protected Areas (by type) per Sub-basin

Next we isolated the areas of basins upstream of the downstream most dam to look for variations between the entire basin and the areas upstream of the downstream most dam. The idea was to be able to further differentiate between breaks and connectivity of every basin, with the general assumption that dams in the headwaters of systems were more disruptive to the system than dams near the confluence to the

Amazon. Below is a map showing the upstream sections and the Protected Areas clipped to those areas:

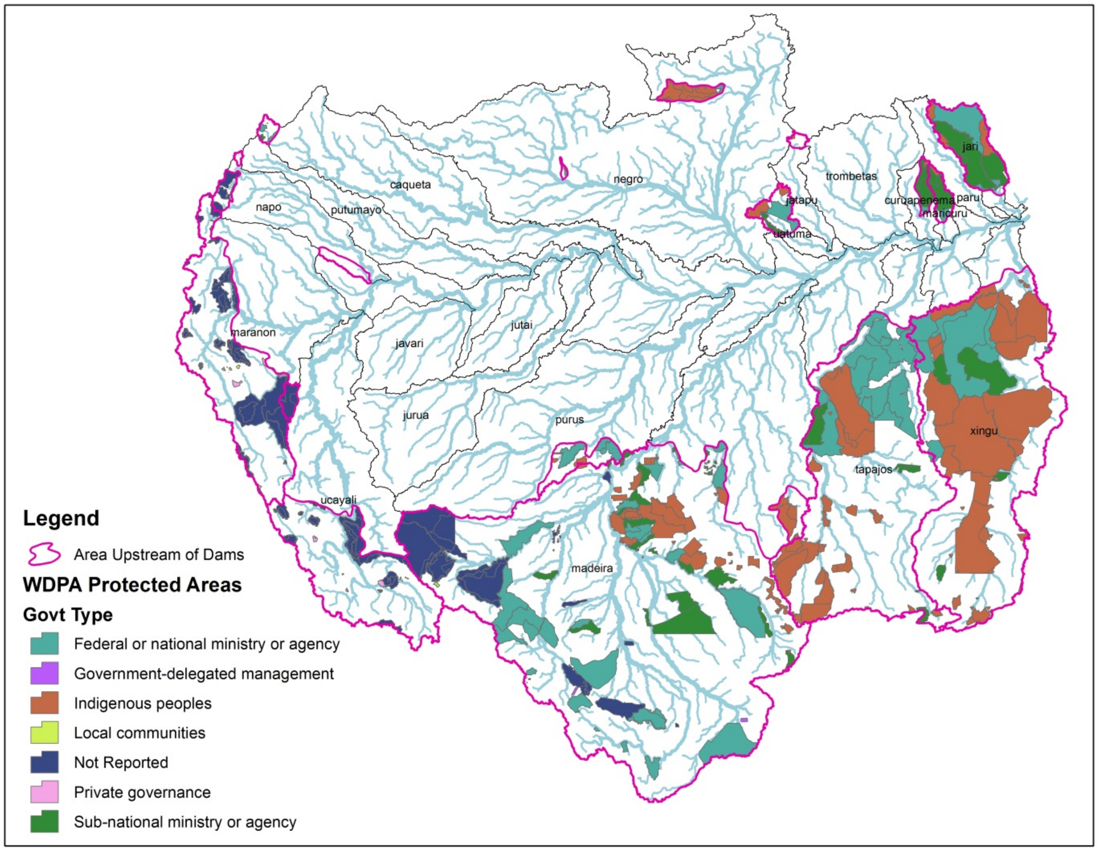


Figure 40: upstream sections of Dammed Basins with Protected Areas

Using the same idea of figure 40 we produced the Percentage of Protected Areas (by type) per upstream section of every sub-basin.

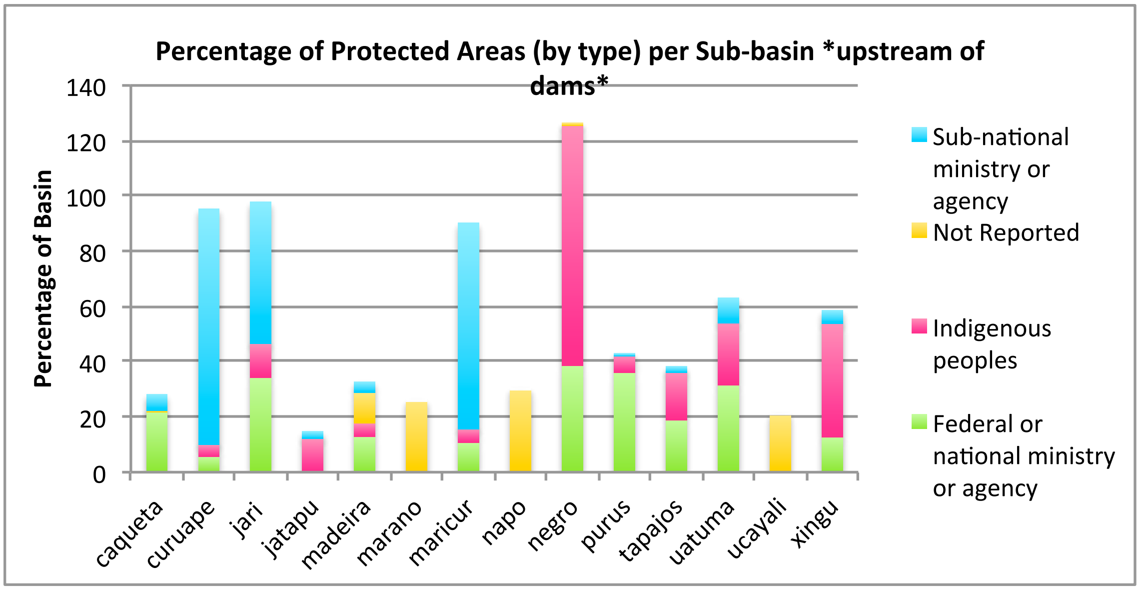


Figure 41: above is a chart showing the Percentage of Protected Areas (by type) per sub-basin upstream of the downstream most dam. Notice that there are 6 fewer dams below representing the 6 basins without dams. Also – the Negro provides an example of overlapping PAs, which explains the 125% of the basin.

Aggregated to a percent of basin value, below is a choropleth map illustrating the percent of basins covered by some type of PA. We notice that the basins north of the main reach of the Amazon are covered by more PAs than other parts of the basin. This of course, does not necessarily indicate greater protection, however, for the purposes of this study, it is assumed that more protected areas offers more protection in the long term.

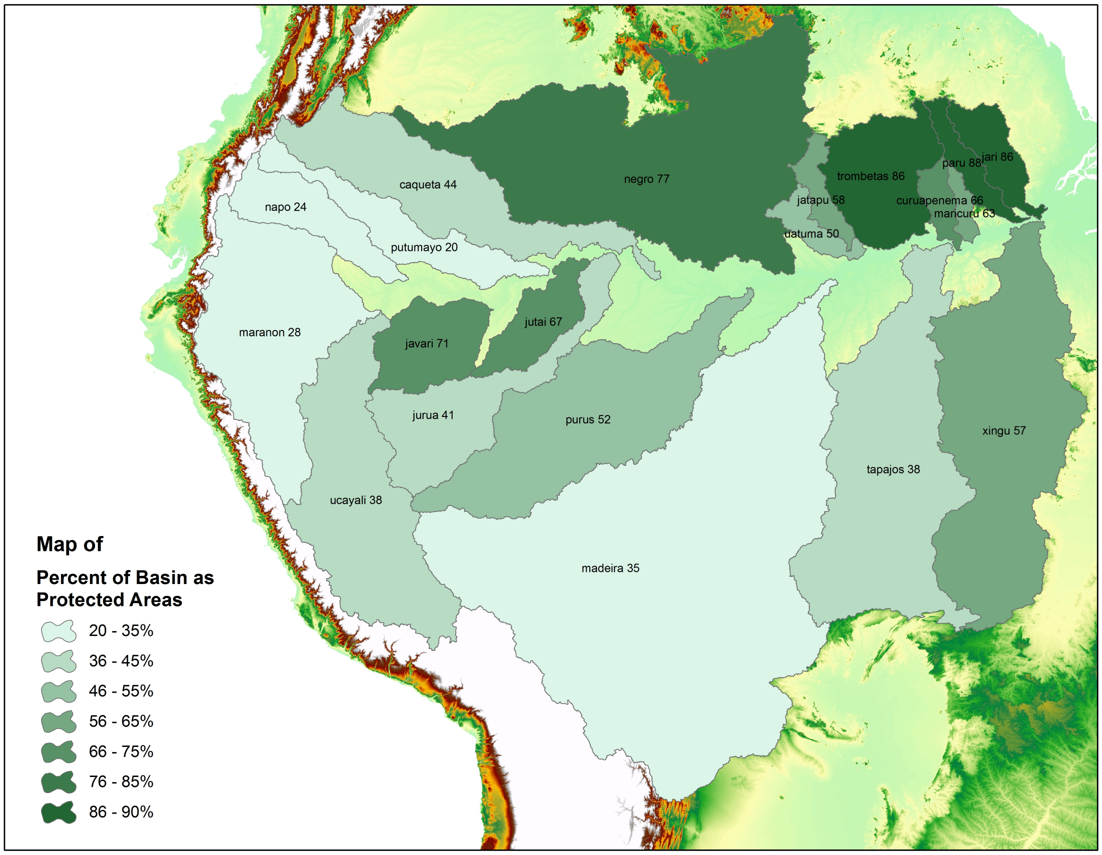


Figure 42: Choropleth map of percent of basin by Protected Area

5.4 Basin Areas: Upstream vs. Downstream

Colored below are the areas within each individual sub-basin, which are upstream of the upstream most dam. Worth noting in the map below is that the circle (denoting location of dam) is symbolized according to potential power generation in megawatts. Below that map is a chart showing area of each basin both upstream and downstream of the downstream most dam. Take for example the Negro vs. the Xingu and one can easily visualize that in the case of the Xingu, (and also Tapajos) there is nearly the same amount of area upstream as there is downstream of the dam – which does not indicate the dam is in the middle of the system, but rather that is near the end of the river.

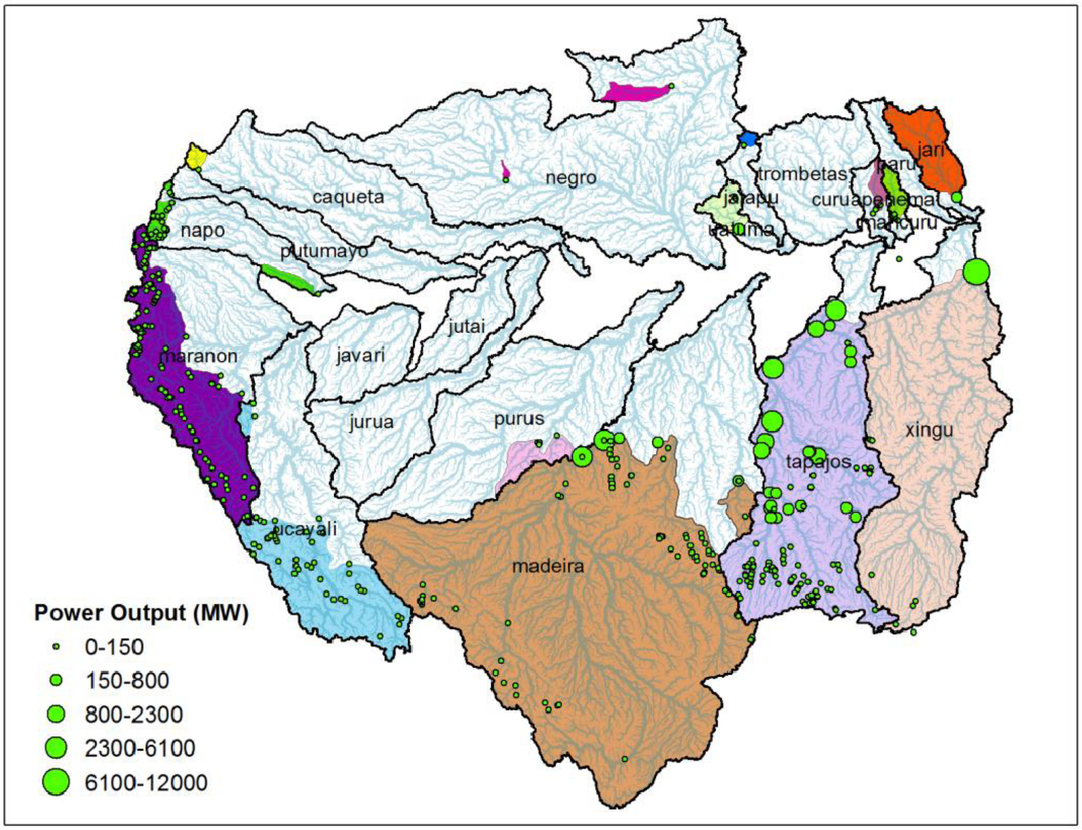


Figure 43: Basin areas upstream vs. downstream with dams by power denoted

Analysis from above Map found below:

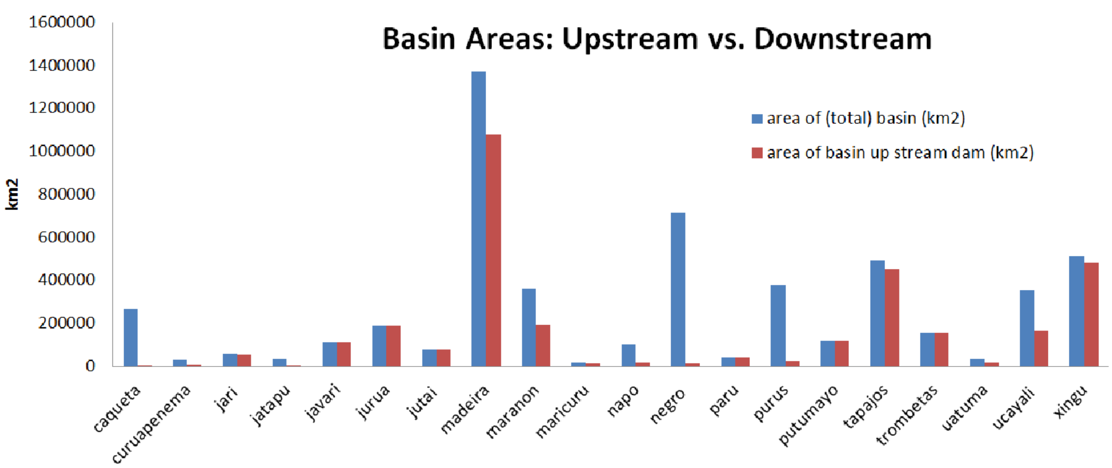


Figure 44: Chart of basin areas upstream vs. downstream

The Negro (from the discussion on page 81) on the other hand has a huge discrepancy between its values indicating that the area upstream of its dam is very small compared to the entire basin.

5.5 Results of Assessing Impacts at a sub-basin level

In order to assess impacts of hydroelectric dams on sub-basins in the Amazon basin, we used vulnerability indexes. The design of these indexes was to assign weights to certain sub-basins given certain criteria. Of the variables previously mentioned collected and calculated at a per basin level, we first measured a multivariable analysis based on the idea of *Available Threat.* The idea of available threat is based on the assumption that those areas with more protected areas will be less vulnerable than those with less protected area. In addition to protected areas, we also assume that those areas that are more deforested are less vulnerable, because there is less potential to disrupt (for the first time) ecosystems. Based on these broad assumptions, subtracting Protected Areas from Deforested areas we arrive at the area available to threat. This number plotted as *Percent of Basin available to threat* was plotted along the X-axis. Along the Y-axis we plotted the *Percent of Basin Upstream of Dam* which was calculated by taking the area upstream of the downstream most dam divided by total area of the sub-basin times 100. The assumption with this metric was that downstream effects of dams will be more disruptive to the fluvial basin and therefore the further upstream a dam is within a particular basin, the more threatened that basin is. This of course makes assumptions that do not take into account each individual system's unique characteristics, however, for a basin wide study this was the decided metric. Below is a plot to visualize this calculation:

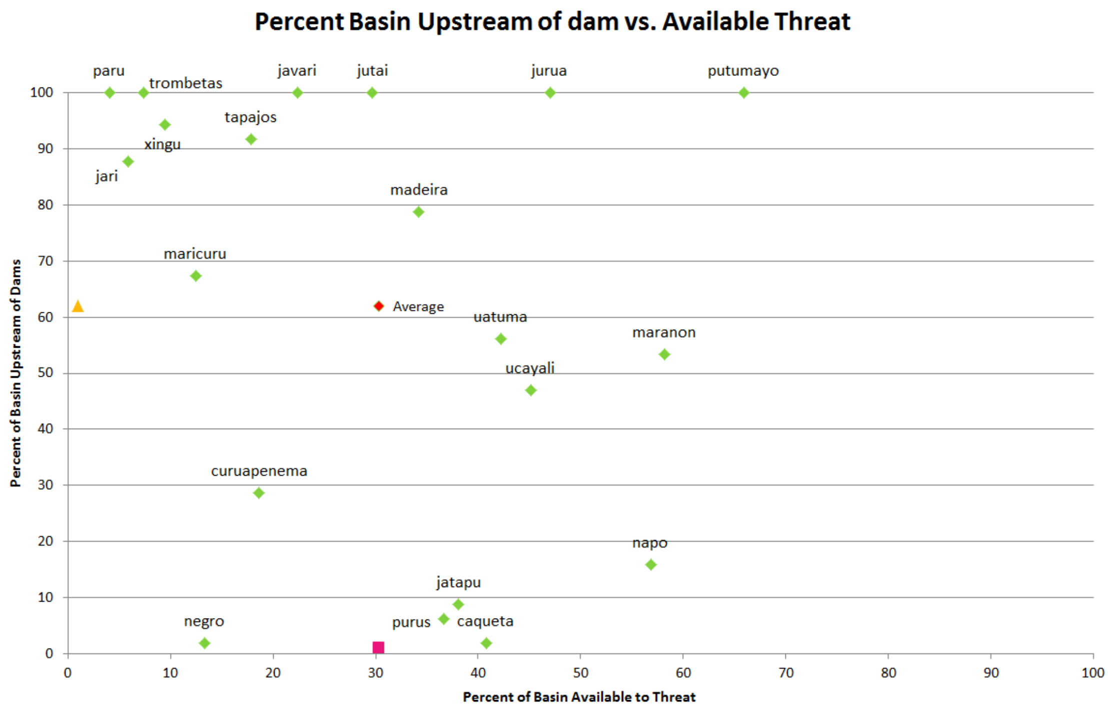


Figure 45: Available threat relative diagram of 20 sub-basins

Plotted above are the *Percent of Basin available to threat* along the X-axis and axis the *Percent of Basin Upstream of Dam* along the Y-axis. What this graphic demonstrates is where each basin stands with respect to other basins although, as mentioned these numbers are based on percent total of each individual basin. This is a potential improvement for this study. The six basins along the top of this chart are the six basins without dams, which explain the percent of basin upstream of dam being 100. The average percent of basin upstream of the downstream most dam is a little over 60%. Another point that is not taken into consideration in this calculation is shapes of basins, which do differ across the basin, and this constraint may bias these numbers as they are given in percent of area. In order for a basin to score poorly using this index i.e. a basin which is highly vulnerable, would be a basin who resides low on the Y-Axis and far right on the X-axis. An additional variable that we wanted to introduce was river fragmentation in order to look at effects on the basin as a whole based on the assumption that dams further downstream would have fewer negative impacts on the basin than dams upstream.

5.6 River Fragmentation

As a baseline, below is a chart showing the Percent of Major Tributaries affected by dams

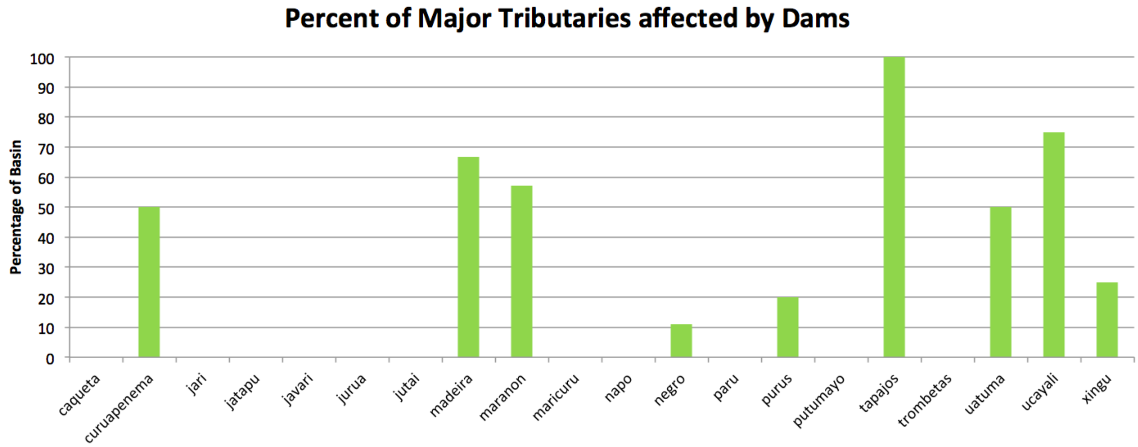


Figure 46 Percent of Major Tributaries affected by Dams

Next we compared the river lengths (upstream and downstream of dams) seen below:

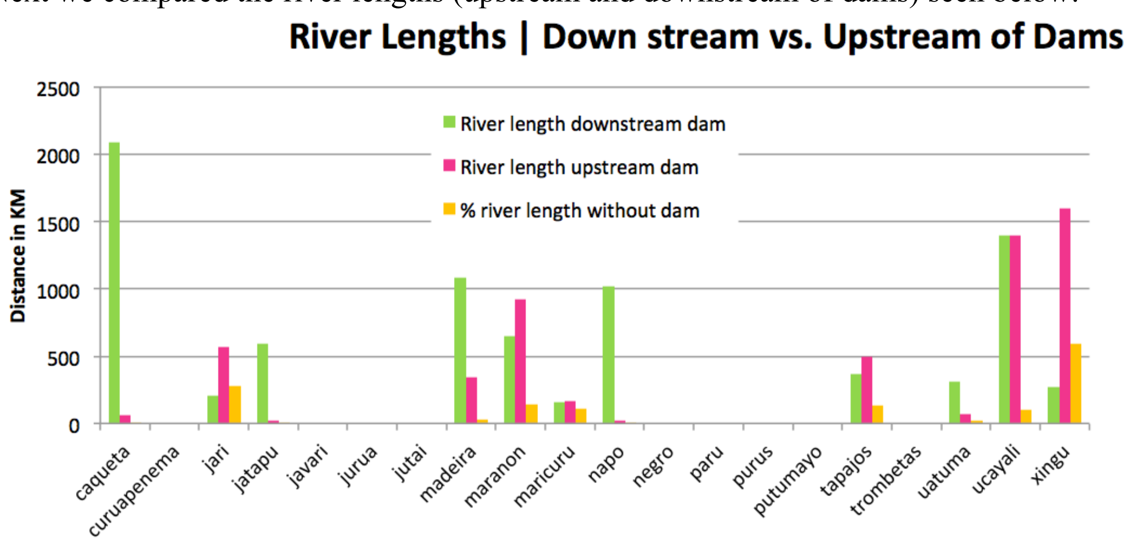


Figure 47: River lengths upstream and downstream of Dams

With figure 47 we assume that with a larger *Percent river Length Without Dam (orange bar)* indicates less vulnerability to the basin. Therefore basins like the Xingu and Jari with relatively high *Percent river Length Without Dam* numbers indicate that these basins will less impacted by dams than basins like the Ucayali, Marañon, and Tapajos whose numbers of *Percent river Length Without Dam* are small.

An additional indicator that was interesting to look at was number of dams on main channel in terms of planned vs. existing.

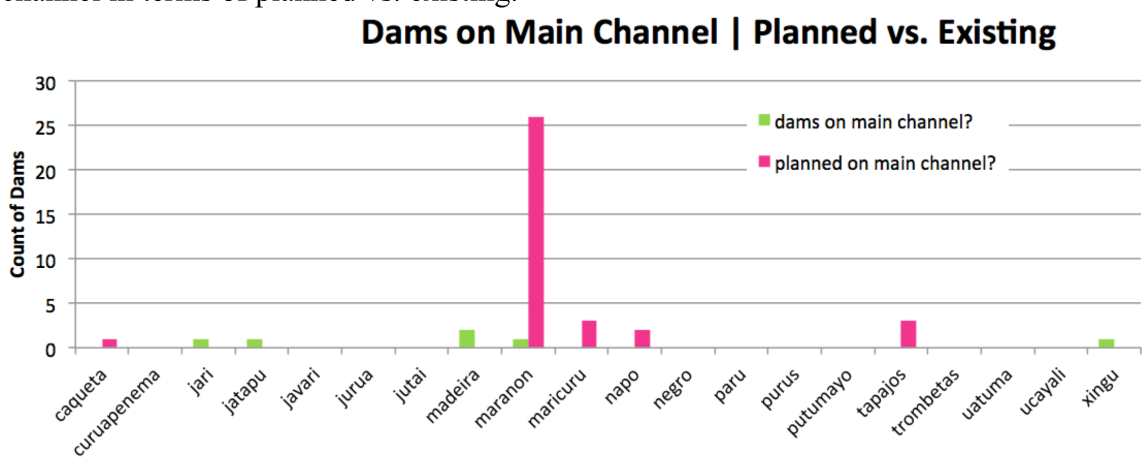


Figure 48: Dams on main channel Planned vs. Existing

Results from the above figure indicate that basins like the Caquetá, Maricuru, Napo and Tapajos and to a lesser extent the Marañon are basins which have the potential to be protected from large dams that would create the first real break in their fluvial connectivity. On the other hand, rivers like the Madeira, and Xingu who already have large dams on their main channels are already broken.

The map used to derive the values for the charts above is found below:

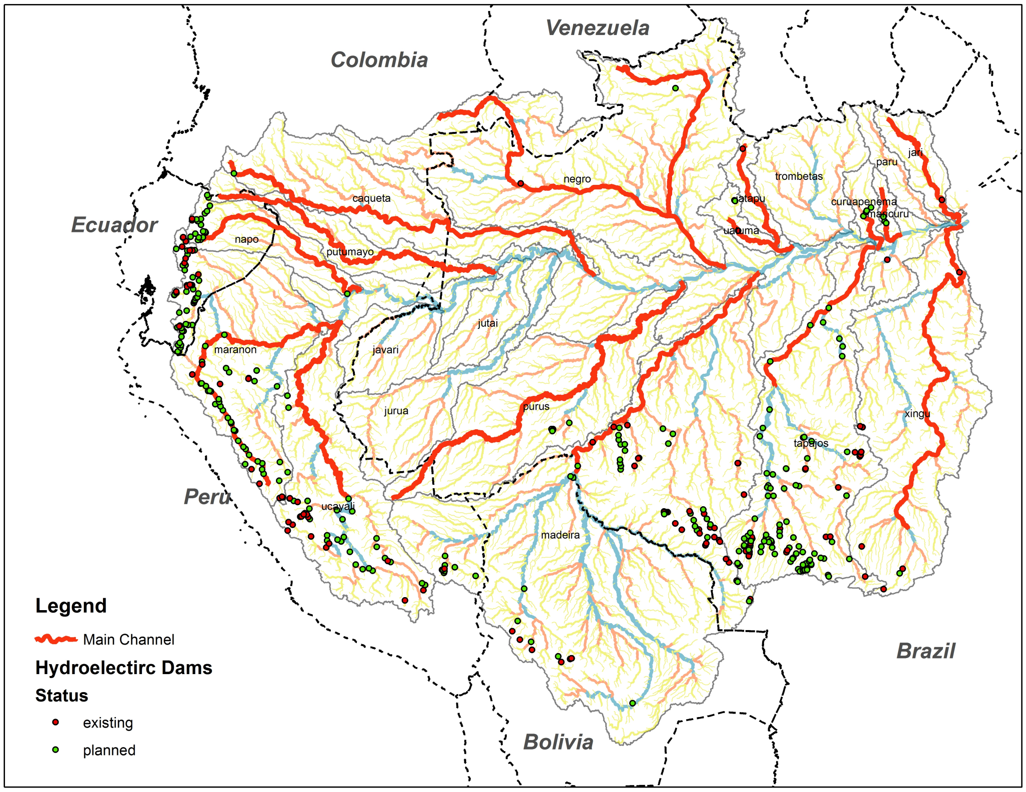


Figure 49: Main Channels of the major sub-basins of the Amazon

5.7: Energy Perspective

As previously mentioned, perhaps the strongest driving argument for hydroelectric dams in the Amazon basin in its most simple form is that the high fluvial potential should be captured via hydroelectric dams to help the developing countries of the basin capture a clean reliable source of energy to help feed their growing economies. While it is understandable from a socioeconomic standpoint of countries focused on economic growth to harness power, there are many fallacies associated with the basic assumptions of clean energy, costs, and social impacts of hydro-power as previously discussed. In fact many of these assumptions that were historically used in the northern hemisphere for clean energy do not hold for dams in the tropics mostly because of the high methane and CO_2 emissions associated with filling reservoirs. Another classic example is miscalculations associated with potential power on systems of high seasonal and annual discharge, which can work against the already financing of mega-projects. Furthermore one should recognize it is common in South America that the energy produced by hydro-electric dams is sold cheaper to extractive industries than to municipalities. This not only undermines one of the critical arguments to build hydro-electric dams in the first place, but simultaneously carries dangerous socio-environmental consequences. Not withstanding, the two charts below were used to quantify the amount of potential energy if all the dams in all basins were to be built. This does not take into account any of the negative environmental or social costs previously discussed. These charts also assume that the potential calculated power is accurate even though as mentioned in chapter two, it is highly likely that these numbers are optimistic.

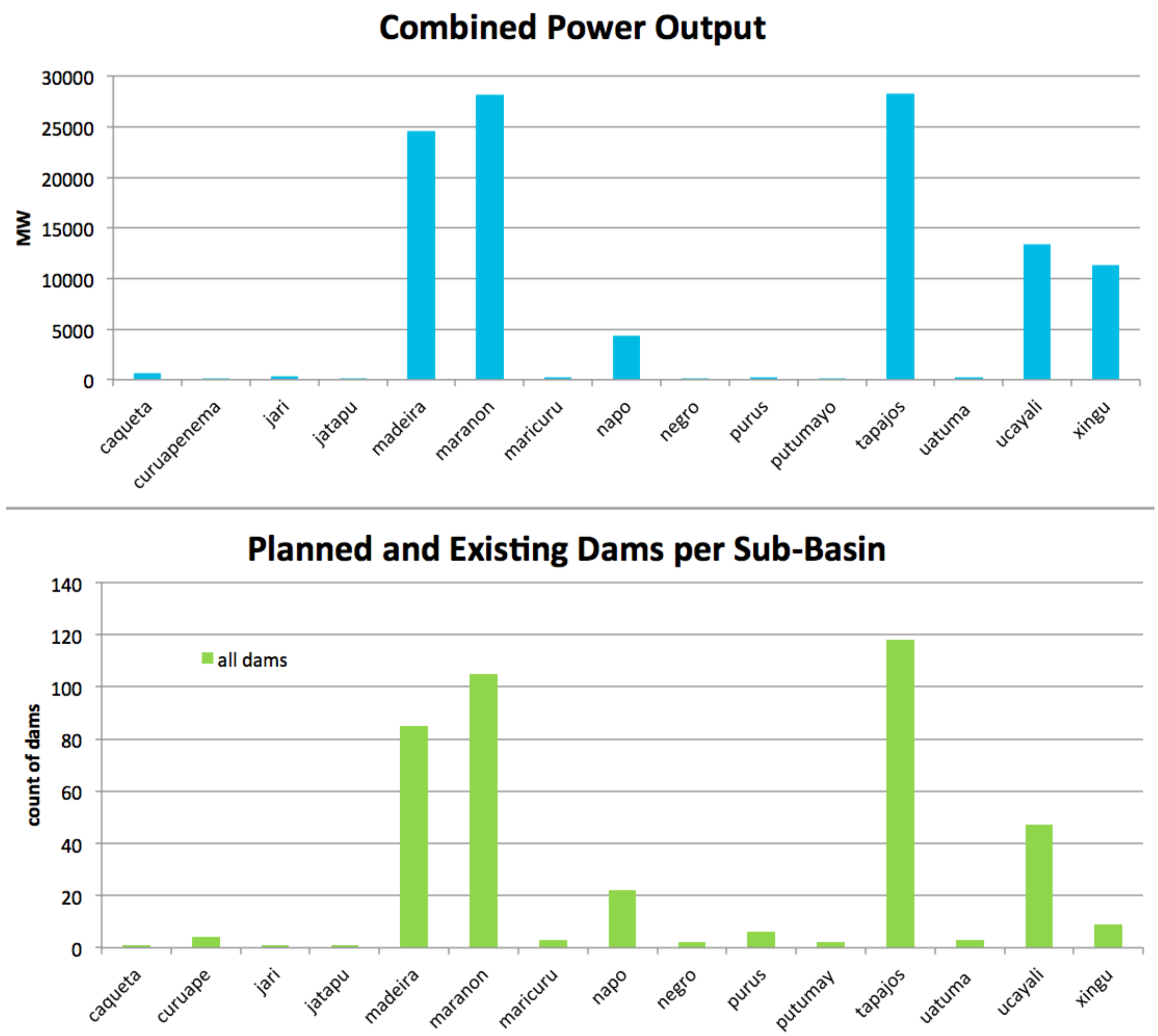


Figure 50: Energy Perspectives- combined power plus number of dams per basin

The above chart does a good job to aggregate the massive deviations within the data of power output and to show that data on a sub-basin level. For example, one can recognize that the there is a genera trend in number of dams and potential power – which is not surprising. However, upon closer inspection it is also possible to not that small variations in the overall pattern add up quickly. For instance, the Xingu's total number of dams (Kaimowitz) is relatively small, however, in terms of potential power production, it is actually quite high (~12,000MW). The opposite is true for the Tapajos whose basin has the highest number of dams (118), but whose potential power output (2,8245MW) isn't that much larger than the Marañon's 105 dams with 2,8138 MW. From another perspective, the Madeira with 85 dams could potentially produce some 24,588 MW which could be seen as proportionately more efficiently than the Marañon.

5.8: Vulnerability Indexes

Variables used in vulnerability indexes were generated for each sub-basin scale to include: [1]Percent of Basin Deforested, [2]Percent of Basin under Protected Area, [3]Percent of Basin upstream of the downstream most Dam (area upstream divided by total basin area), [4]Percent of Major Tributaries affected by at least one dam, [5]River Length, [6]Number of dams on the main channel. A value for each basin was calculated as a percent for each variable. In the case of deforestation and protected areas this was a percent of basin area; for percent of basin upstream affected we divided length of river upstream the dam by total river length; percent of major tributaries affected divided tributaries with dams on them by the total number of major tributaries per basin. Variables, like 1, 4, and 6 assume that with higher their numbers, the basin is at greater risk. On the other hand, variables like 2 and 3 are assumed to decrease risk of a basin as their numbers increase as this equates to more protected area and less downstream dam effects. For the initial vulnerability index we used variables 1,2,3, and 4. For each variable a minimum and maximum value were calculated. A new variable for each of the initial 4 variables was created by taking the value of each variable at every basin subtracted by the minimum value of the set then dividing that number by the difference in minimum and maximum values for the variable. This normalized each variable by 1. The results of the new normalized values were added together to provide values of vulnerability per basin ranging from 1 (most vulnerable) to 4 (least vulnerable). Adding these four new columns together provided the index that ranged from 1.170 (Ucayali) to 3.845 (Trombetas). Below is the static table of the aforementioned vulnerability index.

Sub-basin	Percent of basin Deforested	Percent of basin protected area	percent of basin upstream of dam	percent of major tributaries affected	pbdind	pbda	pbud	pmta	Sum
ucayali	68.33	38.39	47.03	75.00	0.1974822	0.2625	0.4602609	0.25	1.170
madeira	81.06	35.13	78.75	66.67	0	0.2145588	0.7834726	0.3333333	1.331
tapajos	70.71	38.17	91.78	100.00	0.1606435	0.2592647	0.9162421	0	1.336
maranon	64.14	28.92	53.37	57.14	0.2624825	0.1232353	0.5248624	0.4285714	1.339
napo	71.99	24.69	15.98	0.00	0.1407959	0.0610294	0.1438761	1	1.346
caqueta	52.22	44.78	1.89	0.00	0.4473937	0.3564706	0.0003057	1	1.804
purus	35.96	52.06	6.23	20.00	0.6995812	0.4635294	0.0445282	0.8	2.008
curuapenema	42.21	66.11	28.73	50.00	0.6026208	0.6701471	0.2737925	0.5	2.047
putumayo	65.74	20.54	100	0.00	0.2376327	0	1	1	2.238
uatuma	29.27	50.93	56.11	50.00	0.8032673	0.4469118	0.5527817	0.5	2.303
negro	37.37	77.39	1.86	11.11	0.6776697	0.8360294	0	0.8888889	2.403
xingu	56.86	57.24	94.36	25.00	0.3753518	0.5397059	0.9425311	0.75	2.608
jatapu	16.59	58.77	8.86	0.00	1	0.5622059	0.0713267	1	2.634
maricuru	48.76	63.85	67.46	0.00	0.5009866	0.6369118	0.6684329	1	2.806
jurua	43.62	41.85	100	0.00	0.5806953	0.3133824	1	1	2.894
javari	33.28	71.98	100	0.00	0.7411763	0.7564706	1	1	3.498
jari	36.77	86.59	87.8	0.00	0.6870366	0.9713235	0.8756878	1	3.534
jutai	24.45	67.22	100	0.00	0.8780781	0.6864706	1	1	3.565
paru	41.97	88.54	100	0.00	0.6063758	1	1	1	3.606
trombetas	25.10	87	100	0.00	0.8680085	0.9773529	1	1	3.845
min	16.59	20.54	1.86	0.00					
max	81.06	88.54	100.00	100.00					

Table 4: An example of the vulnerability index

The above vulnerability index is designed as an initial index and therefore all four factors, [1]*Percent of Basin Deforested,* [2]*Percent of Basin under Protected Area,* [3]*Percent of Basin upstream of the downstream most Dam (area upstream divided by total basin area),* [4]*Percent of Major Tributaries affected by at least one dam* are equally weighted. Additional weights and factors can easily be added to this index for future investigations in order to calibrate impacts and better assess differences in impacts. Below is a map that allows the visualization of the chart above. This map is symbolized based on six equal breaks with Reds showing the basins that correspond to highest vulnerability based on the above criteria, and Blues indicating basins least vulnerable.

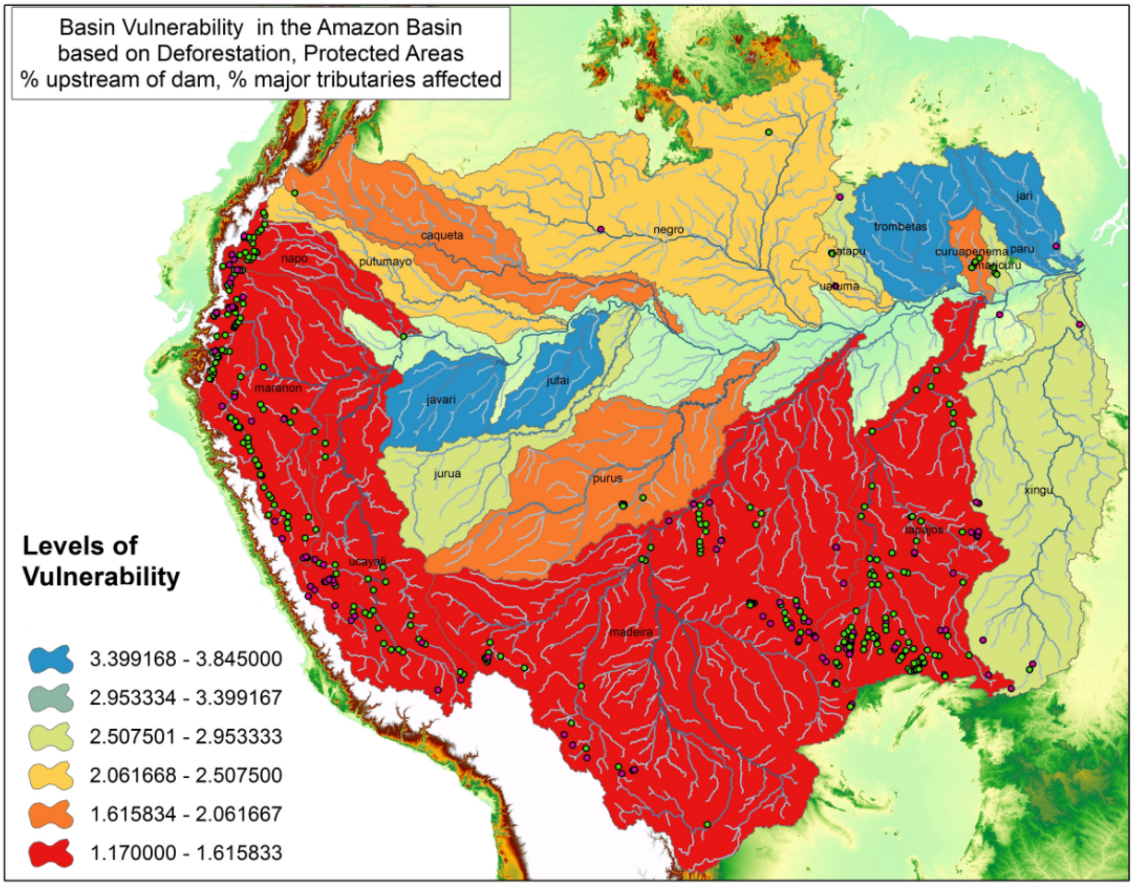


Figure 51: Map of vulnerability of sub-basins in the Amazon

These results indicate several interesting observations. To begin, take the case of the Xingu, which is arguably the most famous case of Amazonian rivers under threat by dams with the long-standing fight over Belo Monte. Based on the vulnerability study previously described, the Xingu basin itself is actually not one of the most vulnerable, despite having the very controversial Belo Monte project. Due in large part to the location of Belo Monte, near Altamira near the confluence with the Amazon, this vulnerability index ranks its downstream impacts on the rest of the basin very small.

Moreover, the Xingu Basin as a whole is relatively well populated by Protected Areas. This ranking however, illustrates a recognized deficiency within this vulnerability index as it is unable to account for nuances in the data such as: losing the archipelagos in the big bend section of the Xingu after damming, and the immediate (and to an even lesser extent, long term) effects to the local indigenous tribes. These two mentioned points however, are points that media and social/environmental activists do pick up on. This example is intended to illustrate that this particular vulnerability index works well for basin level, but was not built to work well with local effects.

This vulnerability study also indicates that international basins are very vulnerable which carries to two important implications. As previously mentioned, many of the dams (perhaps 60%) that are planned or under construction will drive the wedge between Andean and Amazon connectivity for the first time (Finer and Jenkins 2012). What's more, all of the basins along the Andes except the Ucayali are international basins, which complicate policy planning.

Results from the vulnerability index indicate that overall basin health may not be in alignment with current environmental group's major focus on dam construction projects. One example is the Belo Monte Project in the Xingu. As media, NGOs and environmental activists groups work to increase awareness over the Belo Monte project (arguably the most well publicized dam project in the Amazon), results from this study indicate that the Xingu Basin as a whole is relatively well protected in terms of potential impacts on its river basin. Results also indicate that Andean basins (6 of which are international basins) may also face increasing pressure. As previously suggested by Finer et al. (2012), LULC practices in the absence of Protected Areas (PAs) work in conjunction with a massive overall increase of dam construction, and will likely destroy Andean Amazon connectivity. An additional finding proposed by this work suggests that basins north of the main channel of the Amazon (Negro, Trombetas and Jari) have the potential to remain less fragmented than Andean basins and the larger basins draining the Brazilian Shield. This suggestion is especially timely as Colombia recently discussed plans to create an ecological corridor. If created, this corridor has potential to be the largest protected area in the world (http://news.mongabay.com/2015/0303-gfrn-gaworecki-colombia-proposes-corridor.html). It would establish a belt of PAs from the Andes to the Atlantic north of the Amazon main channel, and foster multi-lateral participation between Venezuela and Brazil (https://eyeonlatinamerica.wordpress.com/2015/02/23/colombia-ecological-corridor/).

An important issue that will be addressed in future work is the assumption that more protected areas equates to less vulnerability which may or may not be true as these locations are subject to change, and the WDPA database is subject to uncertainty. Along the same lines, the deforestation rates within basins can be improved in the future with more high resolution remote sensing, this particular study (addressed in greater detail in methods) used a similar approach to the Hansen et al. 2012 paper.

5.9 Transference of Results to Society

The material presented within this paper was laboriously constructed in a multi-relational geo-database, which served the purposes of analysis within this paper and forthcoming pieces. One small example is how each dam point is correlated to a specific Biome, LULC denominator, elevation, distance to roads (1km, 5km, and 50km), type and location relative to WDPAs and political boundaries. The idea is that as time after dam construction passes, more information on the impacts of that dam will be collected. Although each dam site and dam is unique, there are many geo-physical similarities between the sites. Dams that are already built are likely already being studied and these existing dams may share many of the same geo-physical attributes as potential dam sites. An advantage of connecting this information in a multi-relational geo-database (be they academic papers or activist media outlets) is that this information could be used to check for patterns of dam impacts that may otherwise not be obvious.

For instance, below is an example used in the ILASSA35 conference in February 2015 to demonstrate the power of this database. Take the Madeira Basin, which among other qualities is an international basin. Although rivers do not abide by political boundaries, information on dam impacts in an international basin is sometimes affected by these boundaries. In the map below, I ran a serious of filters based on: *Biome, Distance to roads (in this case if there is a planned dam NOT within 5km of a road) Planned vs. Existing and Country.* Alarmingly perhaps, results indicate that there are 25 dams (10 existing and 15 planned) which fit the criteria of being located in: *Moist broadleaf forest, not within 5km of an existing road* and of these 6 are in Bolivia, 16 in Brazil, and 3 in Peru.

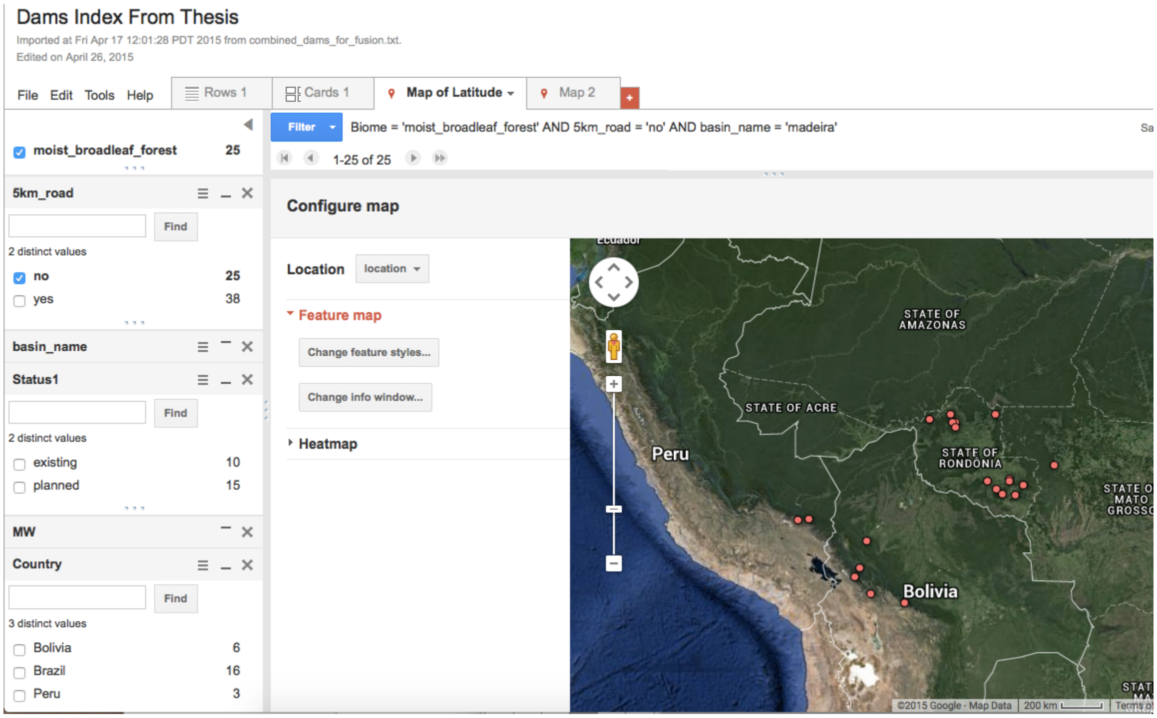


Figure 52 Example of the interface of the geo-database

What this elementary example illustrates is the potential that a multi-relational geo-database has in connecting like attributes of dams across (in this case) international boundaries. As more information from the 10 existing dams in this query is established, it could potentially be used as proxy indicators for predicting future impacts at a higher resolution for the 15 planned dams. There will always be room to refine the query and as better data becomes available, this database may be updated to account for those changes.

Chapter 6: Conclusion

6.1: (Sum) Considerations

One of the most powerful advantages of organizing spatial data in a multi-relational database is the ability to filter information by a range of attributes to look for patterns that may not otherwise be apparent. What's more, depending on the construction of ones database, there can be potential for adding and editing the information in the future. Especially in the case of dam impacts, a multi-relational database can be an extremely useful tool for assessing impacts. As mentioned in previous sections of this piece, one of the problems with assessing dam impacts can be traced to lack of *reliable* information. Other times, there can be an adequate amount of research on a specific dam, however the scope of the research, and therefore the impacts it addresses is extremely focused. The ability to create a platform which would allow information to be cross-referenced spatially has the potentially to link research across disciplines that may not otherwise be connected.

It is also crucial from both an environmental and social standpoint to maintain focus when using this database. In other words, although it is extremely useful to be able to draw connections between dams based on a host of attributes, there is a responsibility to use this information to ask bigger questions. The available information will in turn open conversations about those behind these decisions of construction of mega projects and vision of progress for the six countries most affected by this development. Driven from a visual, numeric, and aesthetic comprehension of the dams in question, one can ask, what are the politics in play? How is neoliberalism transforming South America's geography and geopolitics? Whose interests are being supported by the State, considering that at least four of the six governments in question are part of the so-called New Left movement? Although responding to these inquires was not in the scope of this research, the information is available for further analysis of the neoliberal politics of the South. Additionally, there are other questions circulating at the local level in terms of distribution of power and wealth of the inhabitants of these regions. The challenge to make this type of information legible for rural and indigenous communities that are conducting their struggles for protection their natural resources remains open for further initiatives. It will be imperative to open the dialogue about the data with these populations, and try to incorporate they own visions and comprehension of the space and nature- human relationships in our western models of generating and presenting mapping information. An exchange with current initiatives, such as the project of New Social Cartography of the Traditional Peoples and Communities in Brazil, (Wagner 2013) may represent an interesting point of departure.

Due to the sheer size of the Amazon River, and in turn the projects to dam its tributaries, the impacts are forecasted to be felt at the global scale. However, it is important to consider the driving forces that are asserting construction at a local level. One of the most dangerous combinations surrounding these development projects is when the electricity from a hydroelectric dam is sold cheaper to extractive industries than to municipalities. Not only does this undermine one of the arguments for construction in the first place (see Energy Perspective section) but it also ties those in political power to those extractive industries whose incest may continue without public awareness. This type of economic-political relationship has only very recently begun to make headlines with examples from Dilma Rousseff and Petrobras scandals escalating in spring of 2015. Although activists and academics alike voiced this type of corruption for some time, it is hard to deny the media's influence in bringing these stories to a larger audience's attention. If greater access to information on dam impacts can open a dialogue that transcends those with previously established political leverage, then it is possible to turn the debate of access to clean energy towards a debate on political structures that do not support alternatives.

6.2: What to do and how to focus your work

Threats facing the Amazon's people and environments are today stronger than ever. Historically many academic and scientific papers on dam impacts (and other forms of environmental degradation) target politicians as their audience, with the idea that those setting the political agendas will be the same people who can stop these projects. These reports often fail to reach their intended audience (either based on impenetrable academic text or corruption on the part of the government), and as a result we repeatedly see environmental atrocities take place that were predicted within the literature. Perhaps watching this old system fail as we are witnessing the highest number of dams being built in the Amazon's history, one should think twice about their audience in question when writing on the subject. If there is a chance to change political agendas based on scientific work, perhaps this information should be conveyed to the voters to let them to decide if they agree or disagree with the agenda of the elected officials. One of the ways to enable this type of power is to create an easily navigable user interface connected to a multi-variable database. Allowing people who are affected locally (or regionally) by dam impacts to gain information and visualize patterns associated with dams alters the power dynamics of dam construction projects. When local communities have access to open information, they in turn can pressure (or vote out) politicians responsible for a given project. Altering the flow of information on dam impacts from impenetrable academic literature aimed directly at those directing policy to an open sourced platform shifts the paradigm that those in power have relied on to exploit marginalized groups for the economic gain of few. Changing this paradigm may serve to expose many of the fallacies that were used by politicians to support these mega projects. Opening this dialogue would also make room for a national (and potentially international) debate about the future generation of power, and to what extent hydropower should contribute.

Appendix Material

Figure Present situation showing 121 large hydroelectric dams in the Amazon Fluvial Basin

Figure Future situation showing 406 large hydroelectric dams in the Amazon Fluvial Basin

Table 23.3. Overview of environmental flow assessments and implementation in the four Andean countries. Sources for this information include: Instituto de Hidrología, Meteorología y Estudos Ambientales 2000; Diez and Burbano 2006; Diez and Ruiz 2007; Marc Pouilly and Mabel Maldonado (Bolivia) pers. comm. 2009; Lucia Ruiz (Perú) pers. comm. 2009.

Country	Legislative frameworks for environmental flows	Institutional frameworks for environmental flows	Examples of environmental flow related research to date
Colombia	Article 21 of the proposed new Ley de Aguas defines the concept of environmental flow (Ministerio de Ambiente 2006); Ley Ambiental 99/1993 (and modifications), requires an 'environmental license' for hydropower projects.	The Instituto de Hidrología, Meteorología y Estudos Ambientales (IDEAM) is one of the responsible government authorities for determining and implementing environmental flows.	Environmental flow estimation for the Palacé River downstream from a water diversion using habitat simulation and application of the Instream Flow Incremental Methodology (Diez and Ruiz 2007). Pilot project to determine environmental flows for the Chuza River, downstream from reservoir for water supply for Bogotá using holistic methodology similar to Richter et al. 2006 (P. Tellez pers. comm..). Development of preliminary methodology for estimating environmental flows at water projects that require licenses (Ministerio de Ambiente, Vivienda y Desarrollo Territorial and Facultad de Ingeneria, Universidad Nacional de Colombia, Workshop, October 2008)
Ecuador	The Acuerdo Ministerial No. 155 (Ministerio del Ambiente, 14 March 2007) mentions environmental flows but doesn't provide specific rules for calculation; a new proposed water law also mentions environmental flows. The new Constitution (2008) contains several Articles relevant to water resources management and specifically mentions environmental flows.	The Secretaria Nacional de Agua (SENAGUA) and its basin-level administrative units, the Water Agencies, coordinates with other government authorities to determine and implement environmental flows.	Definition of environmental flows for rivers in the Papallacta system, downstream from water supply reservoirs for the city of Quito using habitat simulation models AndeSim and PHABSIM (D. Rosero et al. pers. comm..). Determination of environmental flows for rivers of the Pastaza Basin, subject to multiple water diversions and flow alterations, using hydrology-based methods (C. Moreno and C. Galárraga pers. comm..; Moreno 2008) and holistic approaches Estimation of environmental flows downstream from a hydropower project on the Topo River using hydrology-based methodologies as part of an environmental impact assessment (ENTRIX unpublished report)
Peru	The current water law, which dates back to 1969, does not make reference to environmental flows.	The Autoridad Nacional del Agua (ANA), based out of the Ministerio de Agricultura, was recently created and will have a role in determining and implementing environmental flows.	
Bolivia	The current water law does not make reference to environmental flows, but the new constitution indicates the need to avoid damage to freshwater ecosystems.	The Ministerio del Medio Ambiente y Agua (MMyA) will have a role in determining and implementing environmental flows.	Research project on application of PHABSIM to study environmental flow requirements for the Beni River and two other systems (C. Ibañéz pers. comm..)

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